SEWAGE WORKS JOURNAL

MARCH, 1935 No. 2

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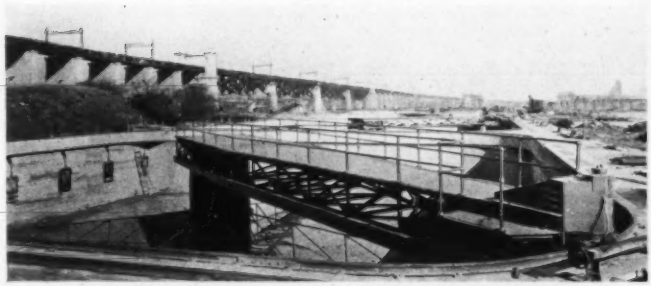

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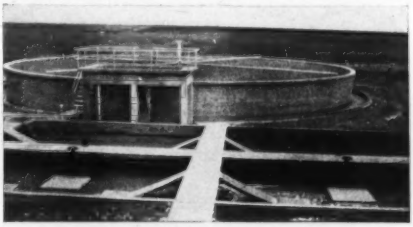

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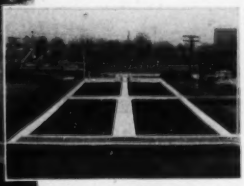

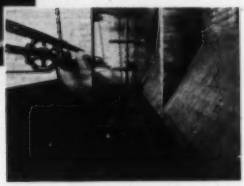

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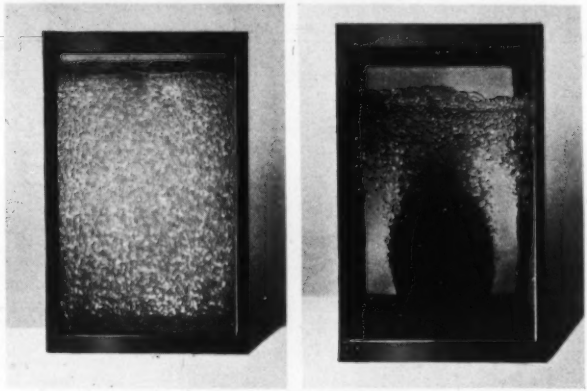

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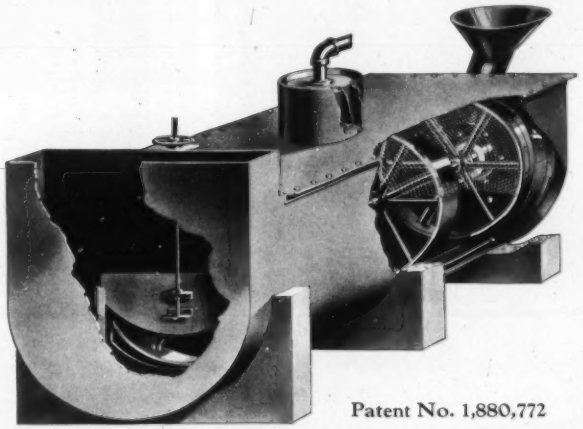

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Federation Affairs

Minutes of the Annual Meeting of the Board of Control Federation of Sewage Works Association

The annual meeting of the Board of Control of the Federation of Sewage Works Associations was held in the office of The Chemical Foundation, Incorporated, 654 Madison Avenue, New York City, on Thursday afternoon, January 19, 1933.

The Secretary called the roll and the following were found to be present in person:

Name	*Representing*
H. G. Baity, Chapel Hill, N. C.	N. C. Sewage Works Assn.
William W. Buffum, New York City	Bus. Mgr.—Member-at-Large
Earl Devendorf (for A. F. Dappert), Albany, N. Y.	New York State S. W. Assn.
C. A. Emerson, Jr., New York City	Chairman, Penna. S. W. Assn.
L. M. Fisher, New York City	Federal Sew. Research Assn.
A. W. Fuchs, New York City	Federal Sew. Research Assn.
Charles G. Hyde, Berkeley, Cal.	California S. W. Assn.
F. G. Merckel (for W. J. Orchard), Newark, N. J.	Member-at-Large
H. E. Moses, Harrisburg, Pa.	Secy.-Treas., Penna. S. W. Assn.
Earle B. Phelps, New York City	New York State S. W. Assn.
W. M. Piatt, Durham, N. C.	N. C. Sewage Works Assn.
Dr. Willem Rudolfs, New Brunswick, N. J.	New Jersey Sew. Conf.
W. J. Scott, Hartford, Conn.	New England S. W. Assn.
John F. Skinner, Rochester, N. Y.	Member-at-Large
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H. J. Darcey, Oklahoma City, Okla.	Oklahoma W. & S. Conf.
V. M. Ehlers, Austin, Texas	Sew. Div. Texas Sect.—S.W.W.A.
W. E. Galligan, Ames, Iowa	Iowa Wastes Disposal Assn.
W. S. Mahlie, Fort Worth, Texas	Sew. Div. Texas Sect.—S.W.W.A.
A. M. Rawn, Los Angeles, Cal.	California S. W. Assn.
J. R. Rumsey, Grand Rapids, Mich.	Michigan S. W. Assn.
H. W. Streeter, Cincinnati, Ohio	Member-at-Large

The Chairman, C. A. Emerson, Jr., presided.

Inasmuch as the Minutes of the annual meeting held January 22, 1932, had been printed in the SEWAGE WORKS JOURNAL, upon motion duly made and seconded, their reading was dispensed with.

The Chairman made a verbal report upon the work of the Federation during the past year, praising the work of the Organization Committee under Chairman Streeter which had been largely responsible for affiliation of two British and one Canadian Association; the work of the Committee on Methods of Sewage Analysis, which, under direction of Chairman Theriault, had perfected methods for determination of the biochemical oxygen demand of sewage; and the work of the Research Committee which, under Chairman Phelps, had undertaken to prepare a commentary on sewage research concluded during the year. Chairman Emerson also commended the work of Editor Mohlman and announced that Industrial Arts Index had promised to include SEWAGE WORKS JOURNAL in the list of scientific journals to be indexed this year.

The report of the Secretary-Treasurer was read and upon motion accepted and approved. From this it appears that the organization meeting of the Federation was held October 16, 1928, when eight (8) associations were elected as affiliates, their total membership amounting to approximately 500. The first number of SEWAGE WORKS JOURNAL was published in October, 1928. Slightly over four years later, at the end of 1932, the Federation had grown to eighteen (18) affiliates; three admitted during 1932 include two British Associations. The aggregate membership at this time is 1425, a growth over the preceding year of 100 and an increase over the 1928 membership of approximately 900. To this should be added 294 non-member subscribers to the SEWAGE WORKS JOURNAL, making a grand total of 1719.

Following this the Business Manager made his report which, upon motion, was accepted and approved. This indicated a deficit for the year, caused chiefly by the cost of issuing the SEWAGE WORKS JOURNAL. Only about one-third of the total cost of operation of the Federation is met by subscriptions to THE JOURNAL, and the balance must come from advertising, in which item the greatest decrease in revenue occurred, amounting to almost 40 per cent, which, coupled with greater printing, editorial, circulation and miscellaneous expenses, due principally to enlargement of the JOURNAL to six (6) issues a year, resulted in a loss on total operations. The increased postage rate was a factor.

Under the heading of Reports of Standing Committees, Chairman Emerson verbally abstracted the report of the Membership Committee, which recited the accomplishments of the Committee during the past year, commenting upon the affiliation of the two leading British organizations in this field, namely, the Institute of Sewage Purification and The Institution of Sanitary Engineers. The report also refers to the organization of a group of Canadian sewage works men, whose application was favorably acted upon at this meeting of the Board. It outlined the plans of the Committee for extending the membership of the Federation during the coming year,

expressing the belief that there is a possibility of growth along this line in the Southern States as well as in some other sections of the United States.

In keeping with the spirit of this report, the Secretary has been directed to request the Secretaries of local associations and the State Health Department Engineers in those states not having an affiliated association to furnish the Business Manager of the Federation with a list of all persons in their respective states interested along the lines of sewage treatment, in order that they may be canvassed as possible subscribers for the SEWAGE WORKS JOURNAL. Upon motion the report of the Membership Committee was accepted and approved.

Chairman Phelps reported for the Research Committee, stating that it was not the thought of this Committee that it should undertake to be arbiters of research, but should be reporters and tell the story of what is being done along these lines, not with the idea of publishing a bibliography descriptive of this work but rather to make available a more or less critical review of the research work being undertaken and to evaluate this work. Considerable discussion ensued and, upon motion duly made and seconded, the Committee's report was accepted and ordered to be published in an early issue of SEWAGE WORKS JOURNAL.

Chairman Emerson submitted the application of the Canadian Sewage Works Association which was applying for affiliation with the Federation, and upon motion duly seconded and carried, the application was accepted and affiliation was approved.

In previous years it has been customary to print in one issue of THE JOURNAL a list of all members. Consideration was given to the desirability, as well as the possibility, of including also the addresses of members and, upon motion seconded and carried, authorization was given for the printing of both names and addresses of members.

The Chairman explained to the Board the establishment of an Employment Service through the medium of the SEWAGE WORKS JOURNAL whereby the Editor will publish a brief statement of the qualifications of those seeking employment in the field of sewage treatment. The Secretary-Treasurer will act as a clearing house for such statements, sent him either directly or by way of Secretaries of local associations, and will furnish employers who make inquiry with information concerning men available. A statement of this Employment Service appeared in the November, 1932, issue of SEWAGE WORKS JOURNAL.

The report of the Executive Committee in the form of the financial budget for 1933 was then presented by the Chairman. This evoked considerable discussion, since it indicated a possible deficit for the forthcoming year. Ways and means of increasing the revenue of the Federation were discussed and suggestions offered. The Business Manager stated that a deficit could be avoided if advertising in the JOURNAL were reasonably in-

creased, and urged that Board members aid along this line by personal effort and by suggestions to the Business Manager. It was decided that THE JOURNAL this year would again be issued in six (6) issues as in the preceding year. Finally, upon motion, the financial budget for 1933, as presented by the Executive Committee, was adopted with authorization to the Executive Committee to take any action in connection therewith that might become necessary during the year.

The election of officers for the ensuing year next followed, and upon motion which was duly seconded and carried the following were reëlected: C. A. Emerson, Jr., *Chairman;* Abel Wolman, *Vice-Chairman;* W. W. Buffum, *Business Manager;* F. W. Mohlman, *Editor.* The term of office of H. E. Moses, *Secretary-Treasurer*, did not expire at this time.

Members-at-Large elected were: W. W. Buffum, H. W. Streeter, Wm. J. Orchard, Lewis Finch, Charles Gilman Hyde.

Upon motion duly made, seconded and carried, the following Executive Committee was elected: C. A. Emerson, Jr., *Chairman;* Abel Wolman, Wm. W. Buffum, Wm. J. Orchard, H. E. Moses.

Pursuant to the provisions of the Constitution and By-Laws, the following committees were selected, and upon motion duly made and carried, they were approved:

Membership Committee: H. W. Streeter, *Chairman*, Cincinnati, Ohio; Anselmo F. Dappert, Delmar, N. Y.; F. H. Dryden, Salisbury, Md.

Publication Committee: C. D. McGuire, *Chairman*, Columbus, Ohio; A. M. Rawn, Los Angeles, Cal.; V. M. Ehlers, Austin, Texas; W. M. Piatt, Durham, N. C.; F. W. Mohlman, Chicago, Ill.

Coördination Committee: L. M. Fisher, *Chairman*, New York City; J. R. Rumsey, Grand Rapids, Mich.; H. J. Darcey, Oklahoma City, Okla.

Research Committee: Earle B. Phelps, *Chairman*, New York City; Dr. Willem Rudolfs, New Brunswick, N. J.; Dr. Max Levine, Ames, Iowa; Abel Wolman, Baltimore, Md.; W. S. Mahlie, Fort Worth, Texas; H. G. Baity, Chapel Hill, N. C.; J. W. Bugbee, Providence, R. I.

There being no further business, upon motion, the Board adjourned.

H. E. MOSES, *Secretary-Treasurer*

Sewage Research

Factors Affecting the Efficiency of Sewage Sedimentation

By G. J. Schroepfer*

Introductory

A common method employed in the separation of suspended particles contained in water from lakes or rivers, in sewage and in the separation and classification of ores and chemicals, consists in the provision of suitable conditions for their subsidence under the influence of gravity. In the case of sewage, sedimentation provides—within limits—an economical and an effective method of removal of suspended matter and oxygen demand.

Within the limits to which it may be controlled or influenced by the requirements of the particular case, or by economics, the efficiency of sedimentation is affected by a number of factors. The problem in design is to consider and incorporate all such factors as may be effective under the conditions of the particular situation, in order to arrive at a design which most advantageously and economically produces the desired results. The following discussion considers raw sewage sedimentation, except where definite statements to the contrary are made. Many of the factors discussed, however, apply also to raw water sedimentation, and final settling in connection with secondary sewage treatment.

The Various Factors Influencing Sedimentation

The factors influencing sedimentation might be grouped under four headings, as affected by:

(*a*) The characteristics of the liquid;
(*b*) The characteristics of the solids;
(*c*) Physical characteristics of the design; and
(*d*) Miscellaneous effects.

Characteristics of the Liquid

The specific gravity and viscosity of the liquid influence the settling of suspended particles. Both of these factors are influenced by the temperature and nature of the fluid. This discussion considers water as the medium.

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Specific Gravity.—The greater the specific gravity of the liquid the more slowly will particles of suspended matter of a given size, shape and weight settle through it. The effect of temperature on the specific gravity of water is shown in Figure 1. The effect of the specific gravity of the fluid is obviously more important for particles whose specific gravity is relatively close to that of water.

Viscosity.—The viscosity of a fluid is defined as its resistance to the relative motion of its particles. It is evident that suspended particles, particularly the smaller and lighter ones, will settle more slowly through a heavy viscous liquid than through one which offers less resistance to the deformation necessitated by their passage through the liquid. The vis-

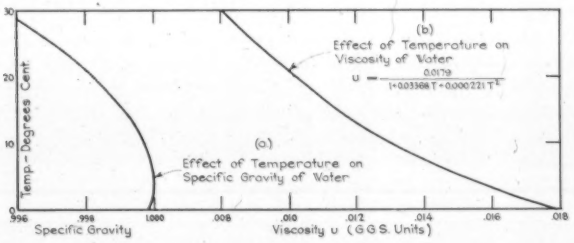

FIG. 1.

cosity of a fluid increases as its temperature decreases, as shown for water in Figure 1. Based on experiments by Poiseuille,[23,*] the relation between the viscosity μ and the temperature T (Centigrade) is expressed: $\mu = \frac{0.0179}{1 + 0.03368T + 0.000221T^2}$. The ratio between the viscosity at any temperature t (Fahrenheit) to that at 50° F., is commonly taken as approximately $\frac{60}{t + 10}$. For particles smaller than 0.1 mm., Hazen and others believe that viscosity controls the rate of settling, and for particles larger than 1.0 mm. friction controls. In the transition space between these sizes both viscosity and friction are thought to be effective.

Relative and Combined Effects of the Two Factors

Both specific gravity and viscosity ordinarily are effective in controlling the rate at which sedimentation occurs. The relative effect of the two factors will depend on the size, shape and specific gravity of the suspended solids, and can be shown in the following manner: Stokes'[13] law for the velocity at which a particle will settle in still water is:

* See bibliography.

$$v = {}^{2}/_{9} g r^{2} \left(\frac{s - s'}{\mu} \right)$$

in which

v = the velocity of subsidence, mm. per sec.,
g = the acceleration of gravity, mm. per sec.^{2},
r = the radius of the particle, mm.,
s = the specific gravity of the particle,
s' = the specific gravity of the liquid,
and μ = the viscosity of the liquid.

Generalizing, we substitute for μ the value $0.013 \frac{60}{t + 10}$ (t being the temperature in degrees Fahrenheit) with v in mm./sec. and d the diameter in mm., and the formula becomes:

$$v = 418 (s - s') d^{2} \left(\frac{t + 10}{60} \right)$$

Assuming sand with specific gravity of 2.65, and of uniform size at 0.1 mm., the formula becomes

$$v = 4.18 (2.65 - s') \left(\frac{t + 10}{60} \right)$$

The values of the two factors $(2.65 - s')$, the effect of specific gravity; and $\left(\frac{t + 10}{60} \right)$, the effect of viscosity, at different temperatures are shown in Table I.

TABLE I

EFFECT OF SPECIFIC GRAVITY AND VISCOSITY ON SUBSIDENCE FOR PARTICLES OF 0.1 MM.—2.65 SPECIFIC GRAVITY

Temperature, ° C.	$(2.65 - s')$	$\left(\frac{t + 10}{60} \right)$	Product	v
0	1.6505	0.70	1.158	4.85
10	1.6505	1.00	1.650	6.90
20	1.6520	1.30	2.150	9.00
30	1.6550	1.60	2.650	11.10
Per cent 30° is of 0°	100	229	229	229

TABLE II

EFFECT OF SPECIFIC GRAVITY AND VISCOSITY ON SUBSIDENCE FOR PARTICLES OF 0.1 MM.—1.20 SPECIFIC GRAVITY

Temperature, ° C.	$(1.20 - s')$	$\left(\frac{t + 10}{60} \right)$	Product	v
0	0.2005	0.70	0.140	0.586
10	0.2005	1.00	0.200	0.837
20	0.2020	1.30	0.262	1.100
30	0.2050	1.60	0.328	1.370
Per cent 30° is of 0°	102.5	229	234	234

Assuming organic solids with a specific gravity of 1.20, and of uniform

size equal to 0.1 mm., the formula becomes $v = 4.18\ (1.20 - s')\left(\frac{t + 10}{60}\right)$, and the values of the two latter factors at different temperatures are given in Table II.

From these tables it is apparent that changes in the specific gravity of water due to temperature exert but a slight influence on the velocity of particle subsidence, especially with heavier solids. Even with lighter organic solids of specific gravity 1.20, the velocity of subsidence is increased only 2.5 per cent, due to specific gravity changes, by an extreme range in temperature of from 0° to 30° C., whereas due to viscosity changes, the velocity of subsidence is increased 129 per cent by the same temperature change.

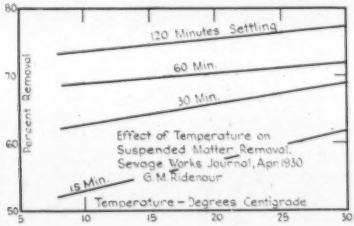

FIG. 2.

From the foregoing it appears that the effect of changes in specific gravity of water with temperature on the hydraulic values of particles can ordinarily be considered as of less importance in sewage sedimentation than is the effect of viscosity changes.

The specific gravity of the fluid does, however, exert another influence

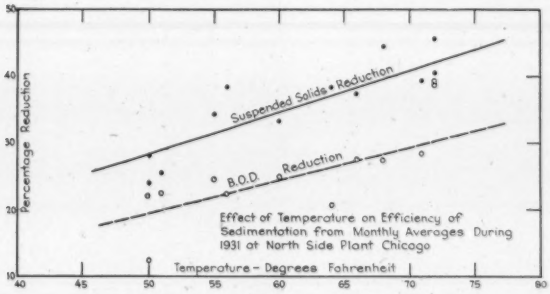

FIG. 3.

which may in some cases be somewhat more important than those previously discussed; namely, its effect on currents and stratification due to the difference in specific gravity of the raw and partially settled water. Currents produced by this cause tend to reduce the detention period in

the tank, and increase the velocity in portions of the cross-section of the tank.

Ridenour[24] observed the temperature effect shown in Figure 2 which indicates that with short settling periods the effect of temperature may be greater than with longer periods of sedimentation. He also observed that above 30° C. a marked decrease in sedimentation efficiency results from increases in temperature. Figure 3 shows the average monthly reductions in suspended solids and 5 day B. O. D. at the Chicago North Side plant plotted against sewage temperature. The correlation of the data is interesting and may be the result of the fortunate fact that the detention periods and sewage characteristics did not vary greatly during this period. The maximum variation in detention period from the average with the exception of one month (when the variation was 28 per cent) was 10 per cent, and in suspended solids and 5-day B. O. D. the maximum variations were 15 per cent and 20 per cent, respectively.

The Characteristics of the Solids

Among the characteristics of the solids which affect the rate of subsidence of suspended particles and the efficiency of sedimentation are the following:

Size, shape, specific gravity and concentration of particles, flocculation, coagulation and coalescence.

Size of Particles.—It is apparent that with a given specific gravity, other factors remaining constant, the larger the particle the more rapidly it will settle in a quiescent liquid. The relation between the velocity of subsidence in mm./sec. (hydraulic subsiding value) and the particle size (in mm.) is not always a constant one. It has been shown by Hazen and others that the velocity of subsidence for sand varies with the particle size in the following manner:

(*a*) 1.00 mm. and larger, as the square root of the diameter,
(*b*) 0.10 to 1.00 mm., as the diameter,
(*c*) 0.10 mm. and smaller, as the square of the diameter.

The relation is shown in Figure 4 for a temperature of 10° C. and particles of various specific gravities. The effect of the particle size is an important factor to be considered in studies of the efficiency of sedimentation basins. Thus, assuming laminar flow, with fixed velocity and linear dimensions of the tank, a particle of 1.0 mm. size will settle approximately 12 times as fast as one of 0.10 mm., and 650 times as fast as one of 0.01 mm., or in a distance equal to the inverse ratio of these values. From a practical standpoint it has been observed that the comminution of particles caused by pumping and the disintegration resulting from a long flow time in the collecting sewers affects the rate at which suspended solids settle.

Shape of Particles.—The shape of the particle affects the rate of particle settling by its effect on skin friction. Since the volume and, hence, the weight varies as the cube of the diameter, and the surface area varies as the square of the diameter, the surface area per unit of weight is seen to vary inversely as the diameter. In other words, the smaller the size the greater the surface area per unit of weight. For a given particle size, a spherical solid presents the least surface area per unit of weight. With angular sharp-cornered particles the surface area and, hence, the skin friction will be greater.

Specific Gravity.—Obviously the heavier the particle the more rapidly it will settle in still water. However, the relation is not a direct one. Stokes and Gilbert[15] have shown that the velocity at which a particle will settle is proportional to the difference $(s - s')$, where s is the specific gravity of the particle and s' the specific gravity of the fluid. Solid particles in sewage have a specific gravity varying from that of sand (2.65) to that of floating material (less than 1). Considering water at its maximum density (specific gravity 1.00), the hydraulic subsiding values of particles of various sizes and specific gravities as shown in Figure 4 are as follows:

	Hydraulic Subsiding Values in Mm./Sec.* with Particle Diameter of:			
Specific Gravity	0.05 Mm.	0.10 Mm.	0.50 Mm.	1.00 Mm.
1.1	0.17	0.47	3.30	5.90
1.2	0.35	0.94	6.60	12.00
1.5	0.85	2.40	16.50	29.00
2.0	1.70	4.70	33.00	55.00
2.65	2.90	8.20	53.00	100.00

* To convert to feet per minute, divide by 5.1.

From the table it is observed that doubling the specific gravity from 1.1 to 2.2 increases the hydraulic subsiding value approximately 12 times.

It is a matter of common observation that the specific gravity of the solids contained in a liquid exerts an important influence on the rate at which the particles will settle.

Concentration of Particles.—The concentration, or density, of suspended particles in a fluid affects the efficiency of sedimentation to some extent. This action is believed to be principally one of the cohesion of particles and their joining together into larger ones with a consequent higher hydraulic settling value. The action may, therefore, be a combination of the effect of the size of particle and flocculation.

Concentration is likely to affect sedimentation in another way, and that is because of the relatively higher specific gravity of the raw influent containing a large quantity of suspended particles, compared with the partially settled water already in the tank. It has been frequently observed that raw water carrying a heavy concentration of particles

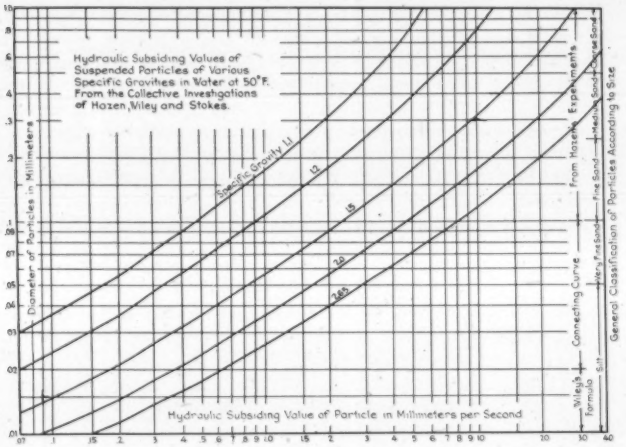
Hydraulic Subsiding Values of Suspended Particles of Various Specific Gravities in Water at 50°F. From the Collective Investigations of Hazen, Wiley and Stokes.
Specific Gravity 11
12
15
28
Diameter of Particles in Millimeters
Hydraulic Subsiding Value of Particle in Millimeters per Second
From Hazen's Experiments
Wiley's Connecting Curve
Stokes' Formula
Fine Sand
Medium Sand
Coarse Sand
General Classification of Particles According to Size

FIG. 4.

descends to the bottom of the tank and continues along until part of the sediment is deposited and the water is gradually dispersed with the partially settled water above. In effect, this results in an ineffectual or unfavorable use of settling tank capacity.

The relative importance of the particle concentration in sewage settling

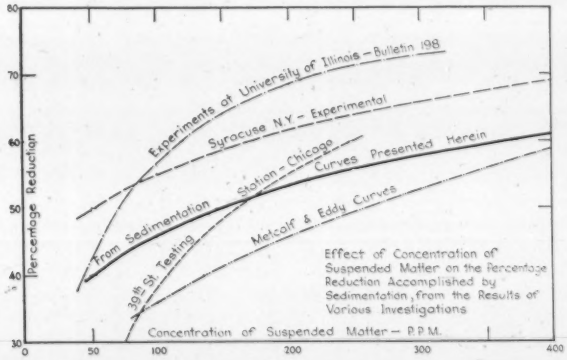
Experiments at University of Illinois – Bulletin 198
Syracuse N.Y. – Experimental
From Sedimentation Station – Chicago
Curves Presented Herein
Metcalf & Eddy Curves
39th St. Testing
Effect of Concentration of Suspended Matter on the Percentage Reduction Accomplished by Sedimentation, from the Results of Various Investigations
Percentage Reduction
Concentration of Suspended Matter – P.P.M.

FIG. 5.

is shown by Figure 5, which shows the effect of this factor in sewage settling for detention periods of 1.5 hrs., indicating that sewage having a concentration of 400 p. p. m. may be expected, under normal conditions, to have its suspended solids content reduced approximately 61 per cent in $1^1/_2$ hrs. of settling; whereas, a sewage with 100 p. p. m. may only have its suspended solids reduced about 46 per cent with the same period of settling, a difference of 15 per cent. Part of the difference may be explained by the variation in the characteristics of the suspended particles in the sewages of different strength.

Flocculation, Coagulation and Coalescence.—Flocculation consists in the natural combination of suspended particles into larger aggregates. Coagulation and coalescence are ordinarily considered as artificial flocculation by chemicals or other means. Flocculation is an important factor in sewage settling. Particles of solid matter in sewage in subsiding come into contact and unite with other particles, thereby forming larger aggregates which settle at a more rapid rate.

Physical Characteristics of the Design

A number of design features affect the efficiency of settling. Among these are:

The detention period provided
Linear velocity of flow: average and bottom,
Depth and ratio of length to depth,
Inlet and outlet effects,
Shape of tank,
Baffling,
Bottom surface area,
Mechanism effects.

Detention Period.—It is obvious that, within limits, the greater the period of quiescence afforded a liquid containing suspended particles, the greater will be the reduction in solids. The relation between the per cent reduction in suspended solids and 5-day B. O. D. and the detention period is not a direct one, as is evidenced from Figures 6, 7, 8 and 9, which show that the reduction increases sharply for a period of time, depending on characteristics of the sewage, and then gradually diminishes until a point is reached at which an increase in detention period does not result in an appreciable increase in solids reduction. From an economic standpoint, a balance exists between the cost of works and the reduction accomplished beyond which it is uneconomical to provide settling capacity. Furthermore, there is the possibility that under adverse conditions too long a period of settling may result in a degradation of the effluent because of septic action and the resulting gas-buoyance of particles.

The substantiating data shown in Figures 6, 7, 8 and 9 consists of

information available to the writer from more than 30 sedimentation plants scattered throughout the United States. A total of approximately 150 values are plotted, each representing a monthly up to a yearly average, with the exception of 10 values which are 10- to 15-day averages. Settling periods shown are based upon theoretical calculated detention periods. The data are separated as shown in the figures into various groups depending

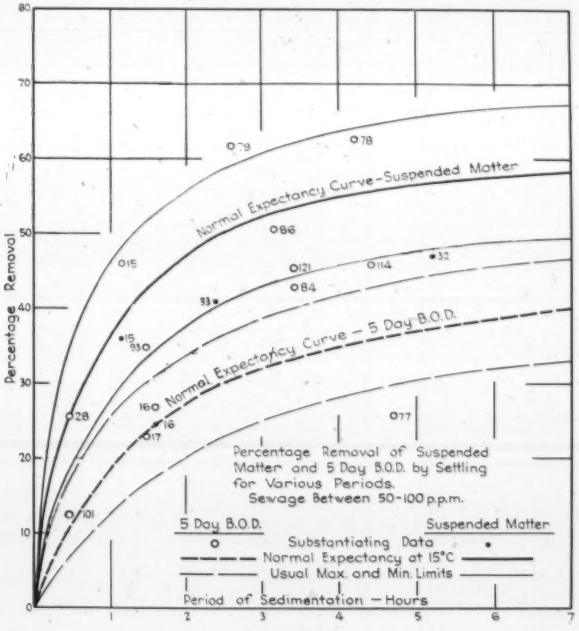
Percentage Removal
Normal Expectancy Curve-Suspended Matter
Normal Expectancy Curve – 5 Day B.O.D.
Percentage Removal of Suspended Matter and 5 Day B.O.D. by Settling for Various Periods.
Sewage Between 50-100 p.p.m.
5 Day B.O.D.
Suspended Matter
Substantiating Data
Normal Expectancy at 15°C
Usual Max. and Min. Limits
Period of Sedimentation – Hours

FIG. 6.

on the strength of the influent sewage, without any attempt at selection or "sifting out" unfavorable data. The substantiating data presented cover a wide variety of conditions such as difference in type of settling tank, and in sewage characteristics and temperature; but in spite of this the data "line up" fairly well.

For those who desire to express the results of sedimentation data in the form of an equation, the following formula expresses the relation

between the normal expectancy in suspended matter removal, R, as shown in Figures 6, 7, 8 and 9 and the period of detention D, in hours:

$$R = C_1 - \frac{C_2}{D + C_3}$$

C_1, C_2, C_3 being coefficients depending on the characteristics of the sewage and of the settling tank. For example, in Figure 7 for sewage between 100 and 200 p. p. m. of suspended matter, the formula has the form:

$$R = 67.0 - \frac{31.0}{D + 0.43}, \text{ to cover the range from 0 to 3 hrs.}$$

Babbitt and Schlenz[8] have found the following relation to exist between the per cent reduction in "settling solids" in sewage, R; and the concentration of solids, C; and the detention period, D in minutes:

$$R = \frac{(D + 226)C}{3.72\left(C + \frac{216 - D}{4}\right)}$$

It is common belief that the detention period provided is one of the most important factors in settling efficiency. In view of this, considerable thought should be given to this factor, in order to be assured that the desired period of detention is actually secured. C. H. Capen[14] in a study of five sewage settling tanks in New Jersey, found that the actual flowing-through time in the tanks was only from 9 to 48 per cent of the theoretical detention period. This means that in these tanks between 50 and 90 per cent of the capacity provided was ineffective as far as detention period was concerned and would probably result in a marked reduction in the efficiency of the sedimentation unit. Baylis[20] and Clifford[19] report flowing-through times of one-fourth to one-sixth of the calculated detention periods for water and sewage settling tanks, respectively. At several sewage treatment plants operators have reported flowing-through times equal to $1/2$ to $1/3$ of the theoretical detention period.

While it may be desirable to provide a zone of quiescent liquid near the bottom of a sewage settling tank, it does not appear necessary or advantageous to devote, in effect at least, $1/2$ to $3/4$ of a tank to this purpose, allowing the sewage to flow through the tank in $1/4$ to $1/2$ of the theoretical detention period or with velocities of 2 to 4 times what may be desirable.

Whatever the underlying cause of the low flowing-through time-detention period ratio may have been in the different plants considered, whether it was caused by short-circuiting, defective inlet and outlet construction, temperature effects or other causes, these observations call attention to the need of careful consideration in the design of sedimentation units so as to secure the detention period desired as well as the utmost in settling efficiency at the minimum of capital outlay.

Velocity of Flow.—High velocities through a settling tank obviously tend to prevent the deposition of solids. The effect of velocity of flow depends on the size and specific gravity of the particles and the linear dimensions of the tank. For illustrative purposes consider two particles of sand 0.50 mm. and 0.05 mm. in diameter as part of the suspended matter in a liquid flowing through a settling tank 15 ft. deep, in which the velocity

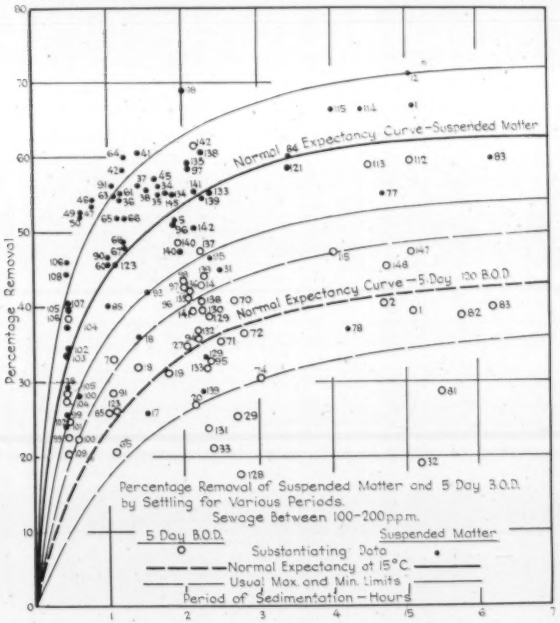
Normal Expectancy Curve—Suspended Matter
Normal Expectancy Curve—5 Day 200 B.O.D.
Percentage Removal
Period of Sedimentation—Hours
Percentage Removal of Suspended Matter and 5 Day B.O.D. by Settling for Various Periods.
Sewage Between 100-200 p.p.m.
5 Day B.O.D.
Suspended Matter
Substantiating Data
Normal Expectancy at 15°C.
Usual Max. and Min. Limits

FIG. 7.

of flow is 8.4 mm./sec. and in which laminar flow exists. (See Figure 11.) The 0.50 mm. particle having a hydraulic subsiding value of 53 mm./sec. will, theoretically, under laminar flow conditions, reach the bottom under the assumed conditions, 2.38 ft. from the inlet wall of the tank. The 0.05-mm. particle whose hydraulic value is 2.9 mm./sec. will reach the bottom 43.5 ft. from the inlet wall. Carrying further to a particle of 0.01 mm. in diameter, the distance at which this particle will strike the

bottom is 817 ft. from the inlet wall. This illustrates the fact that the velocity of flow is more important for particles of low hydraulic subsiding values, *i. e.*, for smaller and lighter ones than for those which are larger and heavier.

Gilbert[15] in a study of the transportation of debris by flowing water determined a relation between the particle size of various specific gravities,

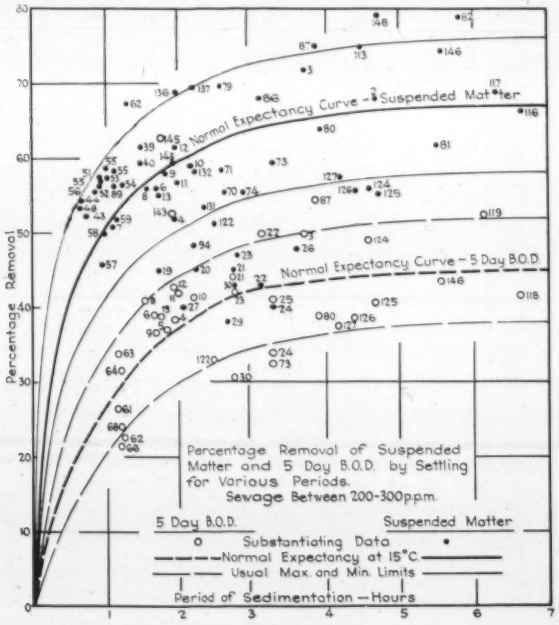
Normal Expectancy Curve – Suspended Matter
Normal Expectancy Curve – 5 Day B.O.D.
Percentage Removal
Percentage Removal of Suspended Matter and 5 Day B.O.D. by Settling for Various Periods.
Sewage Between 200-300 p.p.m.
5 Day B.O.D.
Suspended Matter
Substantiating Data
Normal Expectancy at 15°C.
Usual Max. and Min. Limits
Period of Sedimentation — Hours

FIG. 8.

and the velocities necessary to cause transportation. The results of his study are shown in Figure 10, which indicates that for particles of specific gravity 1.2, 1.5 and 2.5, the velocity necessary for transportation does not vary greatly with size for particles larger than 0.1 mm. but for particles smaller than that size the critical velocity (from a deposition standpoint) decreases rapidly with decreases in size. Since it is ordinarily within this lower range (0 to 0.1 mm.) that we are chiefly concerned in sedimentation

practice, the effect of velocity within this range will be considered in more detail. Considering uniform velocity across the entire cross-section, which may or may not obtain, the following table gives the velocities

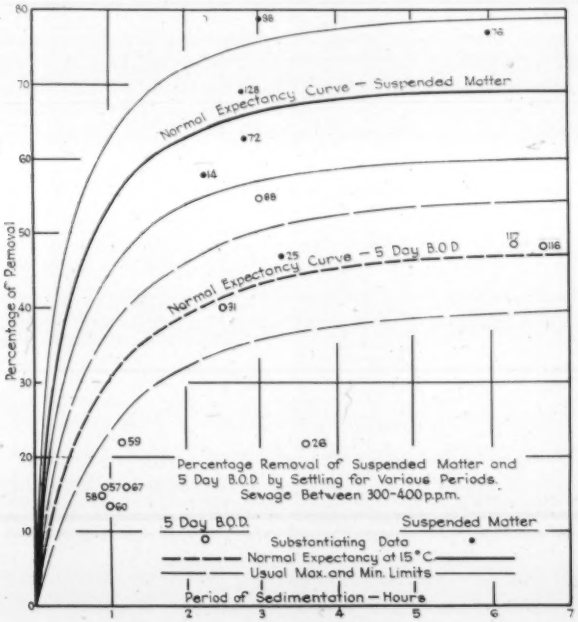
Percentage of Removal
Normal Expectancy Curve — Suspended Matter
Normal Expectancy Curve — 5 Day B.O.D.
Percentage Removal of Suspended Matter and 5 Day B.O.D. by Settling for Various Periods. Sewage Between 300-400 p.p.m.
5 Day B.O.D.
Suspended Matter
Substantiating Data
Normal Expectancy at 15°C.
Usual Max. and Min. Limits
Period of Sedimentation — Hours

FIG. 9.

at which particles of various sizes will settle and the length of tank necessary in terms of tank depth.

Particle Size, Mm.	Velocity above Which Sedimentation Will Not Occur, Mm./Sec. Sp. Gr. 2.65	Sp. Gr. 1.20	Hydraulic Value, Mm./Sec. 2.65	1.2	Distance Required for Particle to Reach Bottom in Terms of Depth 2.65	1.20
0.1	168	67	8.0	0.90	21	76
0.05	140	52	2.9	0.34	48	153
0.01	67	27	0.154	0.019	435	1420

Note: To convert mm./sec. to ft./sec. divide by 305.

Because ordinarily it is impracticable to build a settling tank with length greater than 50 times the depth, and since the ratios of length to depth

in actual practice are generally less than 10, these ratios applied to the hydraulic values will give the maximum value of the velocity so that the particle will reach the bottom before passing out of the tank. These velocities are as follows:

	Maximum Linear Velocity to Allow Particle to Reach Bottom, Mm./Sec.			
	Spec. Gr. 2.65		Spec. Gr. 1.20	
	Ratio Length to Depth		Ratio Length to Depth	
Particle Size, Mm.	10	50	10	50
0.10	80	400	9.0	45
0.05	29	145	3.4	17
0.01	1.5	7.7	0.19	0.95

From this table it is seen that in order to settle out particles down to 0.05 mm. in diameter (which are still classified in size as sand), the velocity

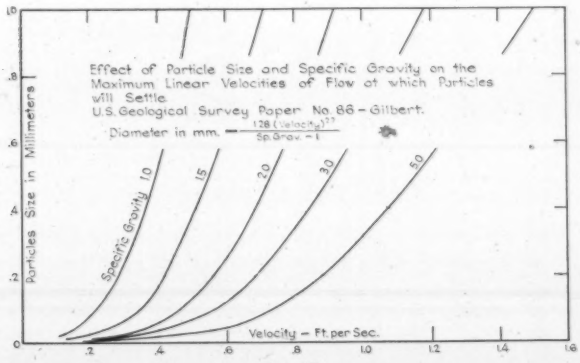

FIG. 10.

of flow should not exceed 30 mm./sec. and 3 mm./sec. in tanks with long ratios of length to depth (10) for particles of specific gravity 2.65 and 1.2, respectively.

It is interesting to compare the above values with those set forth in the literature on sewage sedimentation. Imhoff[13] states that the velocity of flow is negligible when less than 29.4 to 50.5 mm./sec. Fuller[16] feels that the velocity of flow should not exceed 4.3 to 12.7 mm./sec. Smith[21] suggests 5.1 mm./sec. as a desirable maximum velocity. Folwell indicates 12.7 mm./sec. as an upper limit. Babbitt and Schlenz[8] from their studies of sedimentation state that velocity is not important when less than 50.6 mm./sec. In another publication, however, Babbitt[17] states that velocities less than 5 mm./sec. should ordinarily be provided in sewage

settling tanks. The variation in thought (from 4.3 to 50.6 mm./sec.) is quite wide and may represent differences of approximately 0.06 mm. to 0.40 mm. in the size of particle settled out. It appears from a study of the available data that in preliminary sewage settling tanks the velocity should be closer to the minimum values—preferably not more than about 10 mm./sec. (2 feet per minute) for relatively long, shallow tanks—for efficient settling of raw sewage. In final settling tanks following secondary treatment the velocities should be somewhat less. Of course, the velocities provided for in the design depend ordinarily on the reduction desired or necessary. A further reason for designing settling tanks with low linear velocities lies in the fact that in actual operation velocities from 2 to 10 times the theoretical velocity may be experienced because of varying velocities in the cross-section caused by inlet and outlet construction and temperature effects.

The bottom velocity should be less than the hydraulic subsiding value of the smallest particles to be settled. By way of support of this statement, Hazen[6] makes the following statement: "It thus seems a fair conclusion that a bottom velocity equal to the velocity at which a particle would settle through still water would prevent deposition." Metcalf and Eddy[13] state further, however, that while velocities greater than the hydraulic value prevent deposition, once a particle has settled bottom velocities of 20 to 40 times the hydraulic value are necessary to move it along the bottom. High bottom velocities may be caused by temperature effects, inlet and outlet design, or mechanism effects, and are to be carefully guarded against if an efficient design is to be adopted.

Depth and Ratio of Length to Depth.—From what has already been said it appears that these two factors play an important part in sedimentation. In reviewing the literature, however, the author found an extreme difference of opinion among the various authorities as to the influence of depth on the efficiency of sedimentation. Some state that deep tanks are more effective, others that depth is ineffective and still others that shallow tanks are more desirable. In one paper alone (Hazen's "On Sedimentation")[6] the three divergent opinions found expression; Hazen feeling that depth was ineffective while others in discussing the paper held opinions that shallow or deep tanks were more effective. Hazen's statement on the effect of depth is interesting: "the bottom surface area of the basin is important, rather than the depth. . .and sedimentation is entirely independent of depth." Fuller[16] states that "theoretically the depth of the tank is not much of a factor but actually shallow tanks behave better."

Carpenter[18] found a 19 per cent greater reduction in a 2 ft. deep than in a 3 ft. deep tank for sand of specific gravity 2.68, and 9 per cent greater for coal of specific gravity 1.29, all with the same detention period. Bab-

bitt and Schlenz[8] found the depth to affect the percentage reduction in the following manner:

$$R = \frac{(61 - d)C}{0.61\,(C + 40)}$$

in which R = the per cent reduction in settling solids, d = depth in feet and C the concentration of settling solids in p. p. m. For a value of C of 200 p. p. m., other factors remaining constant, the effect of depth from this formula is as follows:

Depth, Feet	Per Cent Reduction In Settling Solids
2	80.7
6	75.3
10	69.8
14	64.4

Babbitt[17] states that theoretically a tank of infinitesimal depth should be the most efficient. The Pacific Flush Tank Company have conducted experiments with sewage in a tank subdivided by horizontal trays into a series of shallow tanks. They state they have been able to pass a quantity of sewage equal to the number of trays in the tank times what can be passed in a deep tank of the same total depth and still secure the same degree of sedimentation efficiency.

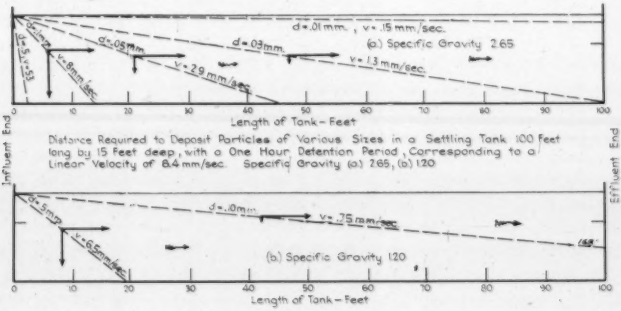
d=.01 mm., v=.15 mm/sec.
(a) Specific Gravity 2.65
d=.05mm.
d=.03mm.
v=.13 mm/sec.
v=2.9 mm/sec.
Length of Tank - Feet
Distance Required to Deposit Particles of Various Sizes in a Settling Tank 100 Feet long by 15 Feet deep, with a One Hour Detention Period, Corresponding to a Linear Velocity of 8.4 mm/sec. Specific Gravity (a) 2.65, (b) 1.20
Influent End
Effluent End
d=.0mm.
v=.75 mm/sec.
(b) Specific Gravity 1.20
Length of Tank - Feet

FIG. 11.

The author is of the opinion that depth and ratio of length to depth exert an important influence on the efficiency of sedimentation of raw sewage. That a shallow tank is more effective than a deep one, some expert opinion to the contrary notwithstanding, can be seen from an examination of Figure 11, which is based upon theoretical laminar flow conditions and which indicates that with a given length and velocity a tank of half the depth shown will collect particles of smaller size than the

deep tank. Figure 12, from experiments on sewage, indicates an increased reduction of 16 per cent with a 2-ft. tank compared to an 8-ft. tank with sewage of 200 p. p. m. "settling solids" and greater increases for weaker sewage. Aside from the direct effect of depth on efficiency of sedimentation, the indirect effects of "short-circuiting" and "dead spaces" because of temperature effects, stratification and turnover, would further indicate the desirability of shallow tanks. Furthermore, relatively long shallow tanks tend to reduce the effect of inlets and outlets, and generally to promote conditions more favorable to efficient sedimentation. It is to be pointed out in connection with statements as to the effect of this factor that they do not apply with equal force to final settling, especially in

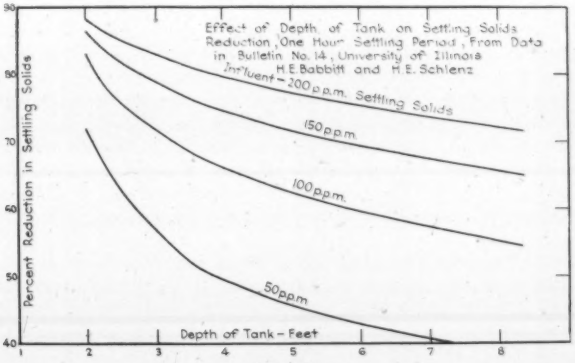

FIG. 12.

activated-sludge plants, wherein the desirability of deep tanks to assist sludge concentration and provide storage capacity is recognized.

Inlet and Outlet Effects.—Although some attention has been given in the design of inlets and outlets for settling tanks, it appears that more study should be given to this feature of the design, as being warranted by its great importance. In the article by Capen,[14] it was stated that the actual flowing-through time as measured by the salt concentration method was only 9 to 48 per cent of the calculated detention period, the explanation that the low ratio was caused by and attributable to—in a large measure—the effects of inlets and outlets appears justified from a study of the data. If an improper design of inlets and outlets results in reducing the effective capacity of a settling basin by as much as only one-half, its importance is clearly evident.

A number of inlet arrangements have been used, consisting of, first, overflow weirs of various types at, or near, the inlet side of the tank; second, gate openings of one type or another, set either at varying or uniform elevations; third, elbowed inlet pipes discharging against baffles or the inlet walls; fourth, miscellaneous types such as a slotted or perforated inlet wall or castings, etc. Generally speaking, all of the types should or do provide baffle walls in an attempt to distribute the flow more or less uniformly through the tank cross-section. The effectiveness and desirability of some of the inlet types sometimes used is open to serious question. Seddon[5] has shown that eddies and disturbances produced by inlets cover a long length of the tank and exist as a factor disturbing sedimentation even after a theoretical long period in the tanks. Some investigators, among whom is Clifford,[19] feel that the inlet design is a question of kinetic energy study, and since the kinetic energy varies as the square of the velocity the latter should be reduced as far as possible.

Since it is desired to produce conditions of uniform flow across substantially an entire vertical cross-section and to prevent partially settled liquor from being mixed with the unsettled incoming fluid—these are two of the ends sought—the inlet to a tank ordinarily is designed with these conditions in mind. Efforts have been made to secure an effective inlet arrangement. In the Elizabeth, N. J., preliminary sewage settling tanks, for example, the inlet wall is perforated along its entire length with closely spaced circular openings. However, unless conditions of distribution in the influent channel outside this wall are such as to provide exactly similar elevation of liquid surface along its entire length, uneven distribution must be guarded against because of the fact that losses through the openings are so small. A number of types, somewhat complicated and costly in comparison with what have generally been used, might be designed. The cost involved in providing efficient inlets appears to be more than justified, considering the detrimental effect on efficiency and detention period resulting from disadvantageous designs.

The most common type of outlet used consists of an overflow weir. Care should be exercised in the location and length of overflow weir provided so as not to produce lifting velocities, induced by the flow over a weir too short for the type of solids expected. In the operation of final settling tanks in the activated-sludge type of sewage treatment plant, some difficulties have arisen, occasioned by the improper location and length of effluent weirs.

Shape of Tank.—Aside from the effects of depth and length of tank already mentioned, several other features deserve consideration. It would appear that a large ratio of length to width (1.0 or more) is definitely desirable in reducing the effects of inlet and outlets, "dead spaces" and in producing a condition of more uniform flow than is ordinarily pro-

duced in tanks with a low ratio of length to width. In addition, the desirability of a high ratio of length to depth is again stressed.

Because of the economics of construction and the requirements of the bottom scraping mechanisms, settling tanks are generally designed in some uniform geometric shape; *viz.*, square, rectangular or circular. A tank which gradually diverges from its inlet to its outlet end at first glance would apear desirable as more nearly fulfilling the requirements of the suspended particles, in that the heavier ones would settle in the relatively high velocity near the inlet end and the lighter ones requiring low velocities would be accorded that condition near the outlet end. Solids accumulation on the bottom would be more uniform. Opposed to this is the fact that a diverging mass of water tends to carry inlet eddies farther and would possibly produce additional eddies, and for that reason a converging tank, from inlet to outlet, would appear desirable as being productive of a more uniform cross-sectional flow condition. However, with the low velocities generally obtaining in settling tanks the latter is not believed to be much of a factor. Furthermore, in view of the complications and cost involved and the requirements of scraping mechanisms, diverging or converging tanks do not appear justified to effect a somewhat questionable greater reduction than can be accomplished in other tanks of equal cross-sectional area.

Baffling.—The provision of proper baffles in a settling tank serves several purposes:

(1) Reduces the effect of eddies at the inlet end of tanks;
(2) Produces a more uniform flow condition and reduces "dead spaces";
(3) Prevents unsettled influent from mixing with partially settled liquor.

The discussions herein presuppose the provision of skimming tanks or of effective baffles to prevent the discharge into the effluent of scum and floating solids.

Properly designed baffles are valuable aids in increasing the efficiency of settling tanks. Metcalf and Eddy[13] state that "good baffling will increase the efficiency of sedimentation by about 25 per cent." Photographic studies of Dr. Straub, Professor of Hydraulics at the University of Minnesota, are interesting in showing the effects of baffling in reducing eddy currents at inlet to tanks. He observed that by moving the baffles toward the inlet end of a tank the influence of eddies could be concentrated, within limits, to the space between the inlet end of the wall and the baffle, somewhat as shown by Figure 13.

Bottom Surface Area.—The effect of the area of tank bottom available for receiving solids has been given consideration. Hazen[6] in one of several propositions considers a tank of depth d being sub-divided by a horizontal

baffle into two tanks of depth $d/2$ from which he concludes that the subdivided tank could handle twice as much water or sewage with the same efficiency of removal as the undivided tank, and that this greater capacity results from the bottom surface area being doubled. He further explains that it is not due to the depth of the tank being cut in half. Others, notably Metcalf and Eddy,[13] have held the same opinion. While the bottom area exposed may exert some influence on the efficiency of sedimentation in certain cases, indications are that this factor is usually subordinate to the influence of depth, and that in tanks as ordinarily designed this factor is not of very great importance.

Mechanism Effects.—Of late there has been a tendency in the design of most sedimentation basins used in the treatment of sewage to provide scraping mechanisms to concentrate the settled solids at one point for removal. The introduction of these mechanisms has introduced a factor in sedimentation efficiency; *viz.*, the effect of these mechanisms on settling efficiency. From what has been said on the effect of bottom velocity, *i. e.*, that a bottom velocity greater than the hydraulic value of the

FIG 13.

particles will prevent deposition, it is evident that velocities and eddies induced by mechanisms which may be traveling at relatively high speeds are likely, under certain conditions, to be a factor in sedimentation.

If a linear velocity of flow near the lower limit of those generally used in practice, namely, 10 mm./sec. (2 feet per minute) is provided, the hydraulic subsiding value of the smallest particles of specific gravity 1.2, settled, may be approximately 1.00 mm./sec. Taking the higher limit of the values suggested by Metcalf and Eddy[13] as causing motion of a settled particle, *viz.*, 40 times the hydraulic value, it would appear that the bottom velocity should be less than 40 mm./sec. (8 feet per minute) to prevent disturbance of a particle of the characteristics considered. In final settling tanks, mechanism velocities somewhat lower than the above value appear desirable from considerations of the type of solids to be settled.

Miscellaneous Effects.—Under this sub-division the following factors may be mentioned:

Currents caused by wind, eddies and difference of temperature,
Bottom reaction,
Electrical effects,
Biological activities.

Currents Caused by Wind, Eddies and Difference in Temperature.—While this factor is one of great importance in affecting the efficiency of sedimentation, it is one over which only a limited amount of control can be exercised.

Wind effects result from the mixing action of settled and unsettled water and from the direct carriage of water from the inlet to the outlet end on the surface of the water in a relatively short time. Observations at various places indicate that the surface velocity produced by wind action varies between 1 and 4 per cent of the wind velocity. Thus a wind velocity of 20 miles per hour, which is one of relatively frequent occurrence in most places, might result in a surface velocity of from 0.29 to 1.17 feet per second. At 2 per cent this value is 0.58 feet per second, or 177 mm. per second, which is exceedingly high considering the hydraulic values of the particles to be settled and the linear velocities of flow commonly used in design. In a tank with a length of 100 feet, some of the incoming water or sewage might reach the outlet end in 2.9 minutes at this velocity. In substantiation of this calculation the following observation is cited. With a wind velocity estimated at 25 miles per hour, the velocity of the surface sewage in a 90-ft. square tank was observed to be such as to cover the distance to the outlet in 2 minutes. The theoretical detention period in this tank was 1.5 hours. Methods effective in preventing this action consist in baffling, provision of high freeboard and the limiting of the size of tanks. Some engineers feel that because of wind effects 100 feet is the maximum linear dimension that should be used in sewage settling tanks.

Eddies caused by obstructions in the tanks such as columns, moving mechanisms, etc., are effective in reducing the efficiency of the tanks when the velocity caused by such actions are greatly in excess of the hydraulic values of the particles. Information is not available on the production of eddies by columns at the comparatively low velocities generally prevailing in settling tanks, but their effect is not believed to be very great, except possibly in the case of high velocities and large ratios of basin obstruction. In the case of mechanisms traveling at a relatively high velocity in a direction counter to the flow of the liquid the effect of eddy formation may be somewhat more important.

When the air and sewage temperature are quite different, short circuiting, mixing and stratification may result. As commonly observed when the temperature of the air is warmer than the liquid, the incoming liquid tends to subside and move along the bottom because of the difference in specific gravity, somewhat as represented in Figure 14 (*a*). Under the reverse temperature conditions the action is shown in Figure 14 (*b*). The action may be one of stratification, which, according to Fuller and McClintock,[16] may occur when the difference in temperature is equal to

or greater than 2.5° F. When the effect of this short-circuiting ceases, vertical currents are set up much as occurs during the spring and fall "turnover" of lakes. This action may occur to some extent due to comparatively small daily variations in temperature, and results in the mixing of unsettled and partially settled liquid.

Bottom Reaction.—Because of the effect of friction, the velocity of the liquid near the bottom is considerably less than that a short distance above the bottom. This tends to produce a lifting action on a particle as it approaches the bottom. The effect of this factor is believed to be very small with the linear velocities of flow ordinarily obtained in sewage settling tanks.

Electrical Effects.—Various investigators contend that electrical charges on the suspended particles affect the efficiency of sedimentation. Ellms[10] has observed that particles of kaolin in turbid Ohio River water have a negative charge as evidenced by a rate of travel of 0.29 cm. per hour, toward the anode with a potential gradient of 4 volts per centimeter. These results are of the same order of magnitude as observed by Whitney

FIG. 14.

and Blake for the migration of particles in a colloidal suspension of silicic acid. The velocity of movement is equal to only 0.00083 mm./sec. for the potential gradient effective, which is too small to affect sewage sedimentation to any extent.

The author is of the opinion that under usual conditions electrical charges on particles of suspended matter in sewage do not influence their rate of sedimentation to a great extent.

Biological Activities.—Biological action may be both detrimental and beneficial; the former by the comminution of particles, resulting from the action of anaerobic bacteria in stale or septic sewage; and the latter from the conversion of organic matter by bacterial and plankton activity into more readily settleable matter. Biological action may exert quite a detrimental effect on sludge deposited on the tank bottom if allowed to accumulate for too long a period, by gas lifting of particles and their passage out of the tank with the effluent.

Summary

It is apparent that the relative effect of the nineteen factors above discussed and their importance in affecting sedimentation varies greatly.

That this is true is evidenced by the fact that the per cent reduction in suspended matter in the 30 plants on which data is presented varied from 24 per cent to 79 per cent. The relative importance of the various factors as herein discussed can be summarized as follows:

(*a*) As affected by the characteristics of the liquid, viscosity appears more important than specific gravity.

(*b*) Under characteristics of the solids, their size, specific gravity, concentration and shape influence sedimentation of sewage, possibly somewhat in the order named. Flocculation and coagulation exert variable effects.

(*c*) The relative importance of various factors affecting sedimentation under characteristics of the design might be placed in the following order: detention period, inlet and outlet effects, depth and ratio of length to depth, baffling, velocity of flow, shape of tank and bottom surface area. Mechanism effects exert either a negligible or a variable influence, depending on the design and operation.

(*d*) Miscellaneous features such as currents and eddies, and biological effects exert some influence. The influence of electrical effects and bottom reaction appear to be negligible factors in sewage sedimentation.

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Additional Comments on Fair and Moore's Article on "Heat and Energy Relations in the Digestion of Sewage Solids"*

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Having carefully considered the reply of Fair and Moore to our discussion of their series of papers entitled, "Heat and Energy Relations in the Digestion of Sewage Solids," we wish to submit the following additional comments.

Fair and Moore, in justification of their basic data, point out that their average gas yield, namely, 1.28 grams per gram of volatile matter digested, is close to that obtained by other workers. The energy results, however, are not calculated on this average value. If they were, then the total change in heat content would be only +1.9 per cent, which is insignificant when one considers the many possible sources of errors. As stated in our original comments, one notes that if the ΔQ_1 values, associated with the experiments in which excessive gas yields were recovered per unit of volatile matter, are disregarded, and those whose numerical values lie within the limits of experimental error are not considered, all the remaining values are found to possess a negative sign, that is, the reaction is found to take place with a decrease in heat energy. While the average weight of gas obtained per gram of volatile matter (fresh solids) was 1.28 grams, the average for Series III was 1.65 grams. The average change in heat content of all fresh solids digestions was +1.9 per cent, while that for Series III was +18.9 per cent. These data vary too widely to be relied upon. In our opinion, Fair and Moore have failed to justify the use of their basic gas data, which, as we have already pointed out, in many cases, show yields far in excess of the maximum possible yield from sewage solids. These excessive gas yields were obtained in spite of the fact that no correction was made for the increase in free and combined CO_2 in the digestion liquors. If carbon balances had been run in these investigations they would undoubtedly have shown recoveries of carbon far beyond 100 per cent. The error probably lies in determining the total solids and volatile matter content of the raw and digested sludges rather than in measurement of the gases produced.

It is true that a few early calculations made by Neave and Buswell which were based on heats of formation and heats of combustion data, showed certain fatty acids to decompose to CO_2 and CH_4 with an apparent absorption of heat energy. No particular significance was attached to

* See THIS JOURNAL, 5, 34 (January, 1933).

these data, for upon recalculation of these reactions using free energy data, all were found to take place with a decrease in free energy.

The lengthy discussions and mathematical developments offered by Fair and Moore in support of their conclusions on the effect of temperature, time, etc., on the course of sludge digestion in batch experiments are worthy of consideration, but we do not agree in all respects with the generalizations based on these data.

We wish to call attention to the fact that all of the data used in these mathematical considerations are based on *batch* experiments, the data from which, as we have already noted, are very inconsistent. We have never found batch experiments to represent the true course of digestion of materials as observed in practice where these materials are fed periodically or continuously into large masses already under fermentation. One need only consult papers in THIS JOURNAL to note wide variations in the rate at which gas is produced in batch digestions of sewage solids. Various ratios of seeding material to fresh solids and other factors affect the initial lag period and the time and rate of digestion very materially. Reference to work done in this laboratory on the effect of various amounts and types of seeding materials on the rate at which sewage digesters may be put into operation is also pertinent.[1] Initial gas production lag periods varying from a few minutes to as much as two months have been noted in batch experiments. In contrast with these lags is the very definite and constant rate of fermentation noted in all continuous feeding experiments where instantaneous seeding and mass inoculation are possible.

In their last paper (p. 761) Fair and Moore introduce for consideration an equation which characterizes the second law of thermodynamics, namely:

$$\Delta F - \Delta H = -T\Delta S \qquad (1)$$

which they rearrange for convenience as follows:

$$\Delta H - \Delta F = T\Delta S \qquad (2)$$

In their subsequent considerations they assume the term $T\Delta S$ to be equivalent to their ΔQ_1. Such an assumption is badly in error. If ΔQ_1 is equivalent to any of the three terms in the above equation it must be ΔH because these values were obtained by subtracting the heats of combustion values of the CH_4 plus the digested sludge from the value of the undigested sludge mixture. These are all heats of combustion values and for practical purposes may be considered ΔH quantities but never $T\Delta S$. The $T\Delta S$ term defines the difference between ΔH and ΔF at a definite concentration, temperature, etc. In addition to this, one's attention is called to the fact that Equation 1 as given above applies only to reversible reactions such as

$$C + {}^1/_2O_2 = CO$$

Sludge digestion, as brought about by the complex life processes of the flora present with the liberation of appreciable volumes of gas, should never be classified as a reversible reaction.

Certain typographical errors are noted in Table I, p. 757–8. They are as follows:

Series II, 40° C., ΔQ_1 should be -26.7 instead of a $+$ value.

Series IV, the sign for the per cent heat change for the 45° and 60° C. values should be $+$ instead of $-$.

The discrepancy between the signs of ΔQ_1 as obtained by using the equation on page 756 and those values as given in Table I, page 757, is still apparent. We agree with Fair and Moore that conventions should be flexible but when this flexibility results in the change *ad libitum* from positive to negative signs and vice versa, only confusion can result.

The article by Keefer and Kratz,[2] published in the last number of THIS JOURNAL, along the lines recently being discussed by Fair and Moore and the present writers is very timely. Keefer and Kratz found a loss of from 58.2 to 185.4 calories of heat per gram of volatile solids added for digestion. If a correction is made for the cooling due to the vaporization of the small amount of water which must be carried off when a gas is liberated from an aqueous solution, and for the cooling due to de-solution of the soluble carbon dioxide (CO_2aq) formed by the bacteria, it amounts, in experiment No. 1, to 75 calories per gram of volatile solids added. The total heat absorbed in experiment No. 1 was only 81.7 calories per gram of volatile matter added. The heat absorbed in experiments 1 to 4B, inclusive, ran from 1 to 2 per cent of the total present at the start. If these data are significant it must mean that the collective errors involved in determining the heat value of the original sludge, the gas and the digested sludge must be considerably less than 1 per cent.

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Authors' Closure

Further Discussion of Fair and Moore's Articles on "Heat and Energy Relations in the Digestion of Sewage Solids"

BY GORDON M. FAIR AND EDWARD W. MOORE

A review of the additional comments by Althausen, Boruff, Buswell and Symons on the series of papers by Fair and Moore on "Heat and Energy Relations in the Digestion of Sewage Solids" impresses the authors with the need for further amplification of their statements concerning the possibilities of experimental errors and for further elaboration of the thermodynamic issues presented in their original papers.[1] The "lengthy discussions and mathematical developments" offered in the authors' papers and in their preceding answer[2] to the comments of the Illinois workers have seemingly succeeded in carrying the point that these discussions and developments "are worthy of consideration." That is all the authors have asked for at any time.

In the original papers attention was called to the possibility of losing gasifiable volatile matter when determining the total-solids content of raw sludge in accordance with present day analytical procedures. Such a loss, if incurred, would be reflected in an abnormally high yield of gas per unit weight of volatile matter destroyed. The very constitution of the gasifiable volatile matter, however, militates against the introduction into the heat balance of errors due to this cause. According to Buswell and Neave's[3] theories of the source of gas produced during decomposition, the gasifiable, or methane-producing, volatile matter is composed mainly of substances of high molecular weight and low volatility. It is precisely these compounds that must be lost in the determination of total solids in order that the heat balance may be affected. The loss of CO_2, or other highly oxidized carbon compounds, or of substances such as ammonium salts and H_2S, can change only the apparent yield of gas per gram of volatile matter destroyed—not the heat balance. The latter is based upon methane production, while the volatile substances most readily lost in the total-solids test presumably produce little if any methane during digestion. This point is emphasized because the determination of the fuel value of sludge requires evaporation of the sludge water and subsequent drying of the residue at 103° C., *i. e.*, the same manipulation as the total-solids determination. To discredit the results of the heat balance, however, it would have to be shown that the analytical procedures result in a loss of substances that are potential producers of methane.

On the other hand, the determination of gas yield per gram of volatile matter destroyed which is relied upon, apparently, to a marked extent

by the Illinois workers requires finding not only the total solids but also the loss on ignition of two samples of sludge. The weakness of the volatile-matter test has long been apparent, and it must be evident that evaluation of the gas yield per gram of volatile matter digested offers considerably more analytical risk than does the striking of the heat balance. Less reliance should therefore be placed upon the gas yield per unit weight of volatile matter digested than upon the heat balance. With reference to the average gas yield of 1.28 grams per gram of volatile matter destroyed, the authors have cited this arithmetic mean value merely as an example of the "substantial harmony" of their experimental results with those of other workers and not as a value to be applied indiscriminately to every batch of sewage solids. Since the ratio 1.28:1 is an average, there must obviously be higher yields as well as lower yields within the experience. Even if it was granted, however, that the gas yields obtained in the authors' Series III, for example, are too high to be reasonable this would not necessarily imply that the heat balance is in error. It should also be pointed out with reference to "the maximum possible yield (of gas) from sewage solids" that the Illinois workers fail to present any evidence, in support of their limiting values, aside from figures adduced by purely theoretical considerations.

Turning next to the thermodynamic issues at stake, the authors cannot understand why the Illinois workers have attached no particular significance to the calculations by Buswell and Neave showing absorption of heat energy in the decomposition of certain fatty acids. Surely the change in heat content, ΔH, of a reaction is a significant property. Nor does the fact that the reaction takes place with a decrease of free energy (ΔF negative) alter its significance. Any reaction that takes place spontaneously must do so with a decrease in free energy. This does not mean, however, that the calculated ΔH, or the finding of an absorption of heat energy, is in error simply because ΔH as determined is positive.

As pointed out by Baas-Beeking and Parks:[4] "As a matter of fact the $T\Delta S$ term in the preceding equation ($\Delta H - \Delta F = T\Delta S$) is frequently rather small and hence ΔH and ΔF are often approximately equal. However, this is not always true, and numerous cases exist where ΔH and ΔF even have opposite signs—*i. e.*, a reaction may proceed spontaneously and be accompanied by the absorption of appreciable quantities of heat."

ΔH is the heat change (absorption or evolution of heat) that would be observed if the reaction ran irreversibly, no use being made of its work-producing power. ΔF is the work that could be obtained if the reaction ran reversibly; *i. e.*, against a chemical potential infinitesimally less than its own, thus permitting it to do the maximum amount of work it is capable of doing. This, of course, would require infinite time for completion of the reaction.

The Illinois workers offer no support of their statement "that the digestion of sewage solids is not a reversible reaction, hence any considerations built around the equation which represents the second law of thermodynamics, namely: $\Delta H - \Delta F = T\Delta S$ is not applicable." If the term "reversible reaction" refers to direction of progress of reaction, it may be well to mention that the laws of chemical equilibrium, comprising a large portion of the science of physical chemistry, are based on the postulate that any chemical reaction or series of reactions may progress in either direction, depending upon conditions. If the term is used in a thermodynamic sense, lack of reversibility implies that the work-producing power of the reaction is not completely utilized, or that the chemical potentials opposing progress of the reactions of digestion are not infinitesimally, but materially less than their own potentials, so that the reactions do not do their maximum work. The second law of thermodynamics, however, still remains applicable in the sense that the heat change to be expected from the reactions lies somewhere between $\Delta H - \Delta F$, or $T\Delta S$, and ΔH; the latter representing the heat change obtained when there are no opposing potentials and the reactions do no work. The reader is referred to the first section of Chapter XIV of Lewis and Randall's "Thermodynamics" (pp. 155–61) for a clear statement of these principles. It should be remembered that we are not concerned with a determination of the degree of reversibility of the reactions of sludge digestion, but only with the setting of upper and lower limits of the heat changes to be expected from them, namely, $\Delta H - \Delta F$ and ΔH. In the fatty-acid reactions studied by the authors both $\Delta H - \Delta F$ and ΔH are positive. This certainly indicates that they are endothermic.

If it were true that ΔQ_1 could be taken as equivalent to ΔH, the computations involved in striking heat balances would be readily accomplished. To make this true, however, it would be necessary to assume that no reactions other than the fatty-acid reactions are accompanied by a significant heat change, and especially that there are no reactions of the type illustrated by the second half of the cycle on pp. 760–1 of the authors' papers, *i. e.*, reactions that utilize the free energy liberated by the fatty-acid reactions. In other words, it would be necessary to justify the statement that the difference between the initial and final states of digesting sludge is measured merely by the destruction of the fatty acids, no other significant change having taken place. The authors doubt that the Illinois workers believe such a statement to be justifiable. If the authors interpret correctly the first portion of Chapter XVIII of Buswell's "Chemistry of Water and Sewage Treatment," this authority states that the digestion process is so complex as to best be represented by a spiral involving reactions of growth as well as of degradation. Reactions of growth consume free energy; they do not liberate it. In this they are

analogous to plant-growth reactions; their source of energy, however, is chemical and not actinic. In view of this fact and the general complexity of the process, it would seem dangerous to conclude that ΔQ_1, which is not a specific thermodynamic quantity, is equivalent to ΔH for the fatty acid reactions. The authors prefer their original statement (p. 761) that the changes observed in digesting sludge from its initial to its final state are brought about both by the degradation, or analytic, reactions that furnish free energy and by the growth, or synthetic, reactions that consume it. If any part of the ultimate difference between initial and final state is accounted for by these free-energy consuming reactions, then ΔQ_1 is no longer equivalent to ΔH for the degradation process alone, nor to the sum of the ΔH values for the two types of processes, but lies between the latter and the sum of the $\Delta H - \Delta F$ values. Its nearness to the last-named quantity measures the degree of efficiency or reversibility of all the reactions.

The reversible cycle discussed on p. 760 of the authors' papers is intended as a simplified representation of a process that involves both types of reaction, which are believed to make up the digestion spiral. Since the cycle is reversible, it represents the upper limit of the heat change to be expected. If the cycle is studied, it will be found that ΔQ_1 is exactly equal to the sum of $\Delta H - \Delta F$ ($T\Delta S$ or heat absorbed) for the two halves of the process. Similar reasoning, the authors believe, applies to the digestion spiral, with the qualification already made in the authors' papers (p. 761) that the process is not thermodynamically reversible, *i. e.*, the free energy is neither developed nor utilized with 100 per cent efficiency. Hence ΔQ_1 will lie between the sum of the ΔH values and the sum of the $\Delta H - \Delta F$ values. The very fact that the two processes oppose one another makes it impossible for either to be completely irreversible; ΔQ_1, therefore, can never be equivalent to the sum of the ΔH values.

In conclusion, the authors beg their readers' indulgence if they proceed a little beyond the scope of the Illinois workers' comments in order to introduce the new and material evidence, relative to the heat budget of digesting sewage sludge, presented by Keefer and Kratz[5] in the last issue of THIS JOURNAL. The authors could hardly have anticipated a better or more timely support of those of their contentions with which the Illinois workers apparently disagree. The work of Keefer and Kratz furnishes direct experimental proof of conclusions drawn by the authors from more indirect or theoretical considerations. Direct measurement of the temperature differences between digesting sludge and its surroundings leads the Baltimore workers to the conclusion that the process of sludge digestion may be exothermic or endothermic, depending upon the stage of digestion reached, but that the over-all process is endothermic. Their

results show, also, that when digestion is most active, as evidenced by gas production, the largest quantity of heat is being absorbed. Consequently the more favorable the conditions (for example, the quality of seeding) for high gas production and rapid digestion, the greater the quantity of heat absorbed; conversely the less favorable the conditions, the longer the lag period, and the less likelihood that the digestion of a given batch of material will show an over-all absorption of heat. The same conclusions were arrived at by the authors in considering their results for Series I, II and III, in which seeding conditions were progressively improved. Series III, which continues to represent, possibly a freak, but possibly also an ideal example of good raw material and good seeding, the lag or exothermic period was much shorter than in the Baltimore experiments. In their first comments on the author's work, Althausen, Buswell, Boruff and Symons[6] advance as their primary evidence to confound the authors' suggestion that sludge digestion can proceed as an over-all endothermic reaction, the "conclusive observations made by Sierp[7] on the heat generated by digesting sludge." Without wishing to belittle Sierp's work which should have the acclaim of a pioneer experiment and has borne fruit by stimulating the researches of Keefer and Kratz, it should be pointed out that the Baltimore work presents definite evidence that Sierp's method of attack—as recognized by most workers at the time of its publication—was unsatisfactory. Attention is also called to the shape of the gas production curves which in their cumulative form trace once again an S-shaped curve—upon which the authors have hinged their mathematical formulation of digestion—rather than a semi-parabolic type of curve that the Illinois workers have believed best represents gasification. The work of Keefer and Kratz, finally, seems to present this question: Is the use of batch experiments, variable as they are, justified in attempts to solve certain problems for which a solution cannot be found in continuous-digestion experiments? The authors believe that the answer should be in the affirmative.

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[1] Fair and Moore, THIS JOURNAL, **4,** 242, 428, 589, 601 (1932).
[2] Fair and Moore, *Ibid.*, **5,** 40 (1933).
[3] Buswell and Neave, Ill. State Water Survey, *Bull.*, **30,** 65 (1930)
[4] Baas-Beeking and Parks, *Phys. Rev.*, **7,** 85 (1927).
[5] Keefer and Kratz, THIS JOURNAL, **5,** 3 (1933).
[6] Althausen, Buswell, Boruff and Symons. *Ibid.*, **5,** 34 (1933).
[7] Sierp, *Ibid.*, **2,** 191 (1930).

Sludge Ripeness Studies. II. The Effect of Pressure on Digested and Chemically Treated Sludges

BY DARRELL ALTHAUSEN* AND A. M. BUSWELL**

Introduction

In a previous communication[1] a preliminary report was given of an investigation of the water-retaining capacity of sludges of varying degrees of ripeness. The present report suggests a formula for expressing this water-retaining capacity and describes in detail the technique for arriving at the values to be used in this formula. The method is shown to be suitable for comparing sludges of different solids content.

Theoretical considerations are presented to show that the effect of aging may be due to an agglomeration of particles equally as well as to a dehydration (loss of "bound water") by individual particles. Moreover, data have been assembled to show the manner in which several other characteristics of each sludge vary with increasing age of the samples in question. Beside these summaries, investigations have been carried out to demonstrate the effect of various reagents upon digested sludges as indexed by their action under pressure. The latter will be the subject of a later communication.

Technique of the Pressure Tests

A tared $^1/_8$ by $2^1/_4$-in. dry felt pad is placed in the bottom of the compression cylinder of a Carver hydraulic press. Fifty grams of sludge are poured into the chamber and a similar pad of felt placed above the fluid. The piston is then inserted and the sample subjected to a pressure P continuously for a time t. During the last fifteen seconds of the run, the exterior of the chamber is quickly wiped dry with a known weight of filter paper. The pressure is then released and the moist parts of the apparatus dried in a like manner. The total water exuded from the fluid cake by pressing is determined by adding that absorbed in the filter paper to the amount caught in a small pan under the cylinder. The weight of the wet cake is calculated by weighing the pads as they come from the press and subtracting therefrom the weight of the air-dry felt pads. Only this net value is used and no correction is made for the initial moisture in the felt itself since this is a constant and would not change the results in any manner. The moist cake is then dried at 105° C. for 24 hours, whereupon the grams of moisture retained are evaluated as well as the total

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solids in the sample. This operation is carried out at one pressure on a number of individual samples varying the time of pressing progressively through the series $2^1/_2$ to 30 minutes.

Plotting the grams of water retained by the cake as ordinates and the time pressure maintained as abscissas, a semi-parabolic type of curve is obtained similar to the solid line AB, Figure 1. Here it is observed that the value of the ordinate, which represents the number of grams of water retained by the cake under a continuous pressure P, gradually decreases with increasing time until this pressure is maintained for thirty minutes. Thereafter, there is no diminution in the water retained by the cake no matter how long the pressure is maintained. That is to say, y' is independent of the time after a certain period, in most cases, thirty minutes.

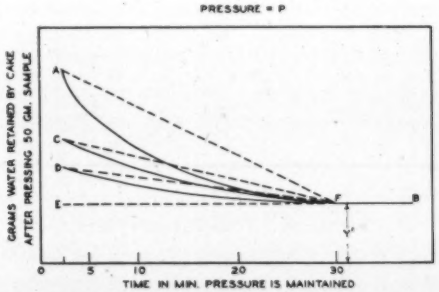

FIG. 1.—General Diagram to Show Effect of Pressure on Sludge at Different Periods of Digestion.

The sludge on which such a series of tests is conducted is then processed for a time under anaerobic conditions. Such a set of conditions is imitated in this laboratory by drawing fifteen-day sludge from the experimental plant into three 4-liter bottles. The remaining air is swept from these containers with methane and a gas trap attached so that no air may re-enter the bottles. These separate tanks are simply allowed to age for any desirable period, when another series of pressure tests is carried out upon this same sludge. This curve, however, does not coincide with the previous one but in part lies below it, thus indicating a higher rate of release. It corresponds then to the solid line CB, Figure 1.

This same sludge is then aged for a still further period and again tested. A third curve is thus produced which indicates a still higher rate of release of water. This curve corresponds to a line, as DB, Figure 1.

It will be noted here that all these curves, although made up of data

derived from a sludge of varying age, nevertheless approach and have the same asymptote, once the samples have been pressed for a period of 30 minutes. This is very important in these studies inasmuch as continued aging does not in any manner reduce the water-retaining capacity of the sludge below this minimum. This technique makes it possible to predict the relative ripeness of a sewage sludge in a very short time, because a well-digested or well-ripened sludge under pressure treatments as herein described has a very high rate of release of water associated with it; moreover, the amount of water retained by its compressed cakes is practically the same at the end of $2^1/_2$ minutes' pressing as at the end of thirty. Old sludge so treated would thus produce a curve approximating

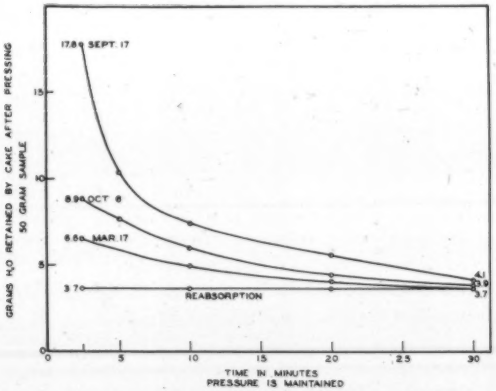

FIG. 2.—Effect of Pressure on a Sludge at Different Periods of Digestion—3000 Pounds.

EB. It is for this reason that we have arbitrarily defined the term *expressible water*, used in these pages, as the difference between the amount of water retained after $2^1/_2$ minutes and 30 minutes of pressing. This value, it will be observed, is inversely proportional to the age of the sludge.

It is further observed that the wet cakes from these runs, once they have been dried at 105° C., if subjected to a high vacuum and then soaked in water will, of course, absorb a certain amount of this fluid. However, when each cake is again pressed the grams of liquid retained are independent of the time that the pressure is maintained and are equal in amount to that retained in the initial pressure tests after 30 minutes' pressing; that is to say, the curve formed by the reabsorption pressure tests corresponds to *EB*, Figure 1. So it appears that a curve coincident

with that of the completely ripe sludge is at once established by this operation, which, of course, will be equivalent to having a control at the beginning of the tests. Thus, the extent of water that will be retained in the thoroughly ripened sample may not only be predicted to begin with, but the comparative degree of ripeness may thus be determined by simply

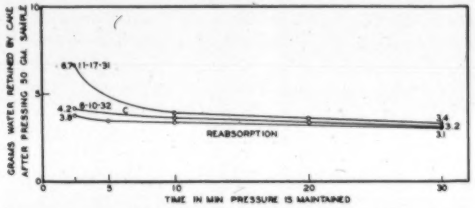

FIG. 3.—Effect of Pressure on a Sludge at Different Periods of Digestion—3000 Pounds.

observing the proximity of the curves furnished by pressure tests on the sludge and that obtained from reabsorption values.

Moreover, since the skeleton of these curves is furnished by the several values at $2^1/_2$ and at 30 minutes, only these determinations need be carried out. Such data gives the dotted lines AF, CF, DF, EF in Figure 1. So we see that as the sludge ripens, AF approaches EF.

Experiments showing the same kind of curves and the same type of results are obtained whether the pressure is 100, 1000 or 10,000 pounds.

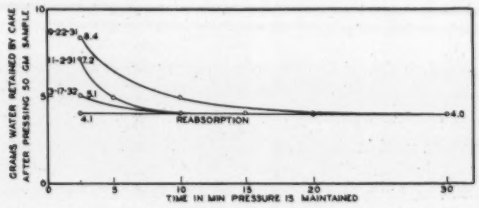

FIG. 4.—Effect of Pressure on a Sludge at Different Periods of Digestion—1000 Pounds.

However, the adoption of any such test would be facilitated by the use of the lower pressures. One thousand pounds pressure and a minimum time of $2^1/_2$ minutes is found to be the most expedient since the cakes are pressed sufficiently rigid under these conditions to remove them from the compression chamber without sludge losses. Pressures greater than 3000

lb. produce curves too near to one another and the experimental errors thus assume too large proportions.

Four hundred individual test runs were carried out using this method

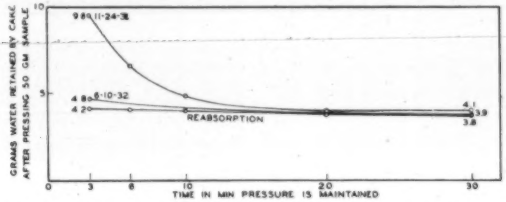

FIG. 5.—Effect of Pressure on a Sludge at Different Periods of Digestion—1000 Pounds.

and it is observed that the runs can be duplicated very closely. Using the water retained in the cake as the criterion, the weight of fluid evaporated from check runs does not vary by more than 0.5 gram, where the total amount retained is 20 to 25 grams. In case the total retained is 3 to 5 grams the results check within 0.1 to 0.2 gram.

However, it should be mentioned that this degree of accuracy is dupli-

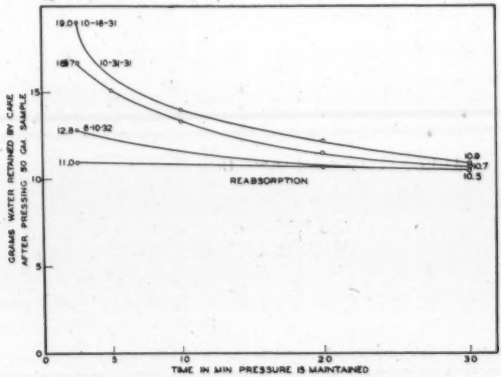

FIG. 6.—Effect of Pressure on a Sludge at Different Periods of Digestion—100 Pounds.

cated only when using a new set of felt pads for each run. Among the filtering media tested were filter paper, pressed cotton, several varieties of felt, gauze, muslin and canvas. A type of woven felt similar to that

used in the Carver presses is the best for this purpose. We found those made from Type X felt of the Continental Felt Company to be very satisfactory. These pads cannot be used indefinitely since their permeability changes materially with repeated pressing, cleaning and drying; and slightly, after being used for as many as three determinations. It is for this reason that all of the results in this paper are not absolutely comparable, but wherever necessary, as in the tests on relative effects of reagents, new pads were employed. In case aging was the only factor investigated, new pads were not always used after the initial tests, for, inasmuch as the porosity of the pads tends to decrease with use, and if the water-retaining capacity of the sludge still showed a decrease on the old pads, this would enhance the certainty of this experiment. The only difference would be in the indication of the relative degree of ripeness, since the decrease in permeability would cause slightly more water to be retained in used pads than in new ones. This is not an appreciable factor until

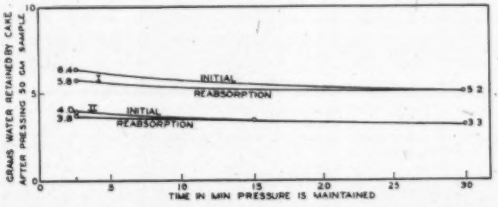

FIG. 7.—Effect of Dilution on Differential $\frac{\Delta v}{\Delta t}$. Decatur Sample—1000 Pounds.

after the pads have been used more than three times, which was never the case.

Data and Discussion of the Effect of Pressure on Sludges at Different Periods of Digestion

Figures 2 to 6 illustrate very clearly the effect of pressure on various 15-day sludge samples obtained from the experimental plant at the University of Illinois. All of these samples show a decreasing tendency to retain water with increasing age. Obviously, the reabsorption curve in each case is an index of the minimum water-retaining capacity approached by the sludge as digestion continues. But plant experiments will best show just how closely these initial curves and those furnished by the reabsorption data on the sludges must approach each other before storage is no longer essential, for practically it does seem likely that these two lines should absolutely coincide. As the result of many such labora-

tory tests a well-digested sample is indicated whenever the differential between the curve from the pressed sludge and that from its reabsorption data is $\frac{|\Delta|}{15} \leq 1$. That is, these tests appear to support the following conclusion. Let A be the grams of water retained by the sludge cake after pressing a 50-gram sample for $2^1/_2$ minutes and B the amount of water retained by the same cake after 30 minutes of such treatment. Then in all thoroughly digested sludges, no matter what the pressure or the percentage solids—

$$\frac{A - B}{30} \leq \frac{1}{15} \qquad (1)$$

Extended experiments may show that it is necessary to modify this fraction but we have found that it holds for all pressures from 100 to 10,000 lb. and for sludges whose percentage solids vary from 5 to 15 per cent.

However, if it is desired to use this test as an index of digestion on two sludges not of the same solids content and obtain comparable indices, both of the stage of digestion and the amount of water retained, the process is complicated slightly but the test is in no manner impaired, as a study of the results of the following typical experiments will show (*cf.* Figures 3, 7 and Table I).

Curve I, Figure 7, is made up from a sludge containing 11 per cent solids. This sample was diluted 1:1 so that it then contained but 5.5 per cent solids and this sludge examined by a series of similar pressure tests. Curve II was constructed from these data. These curves, like all others previously constructed, are composed of the two branches "initial" and "reabsorption." It is ob-

TABLE I

COMPARISON OF EFFECT OF PRESSURE ON WELL-DIGESTED SLUDGES FROM DIFFERENT DISTRICTS

Source	Estimated Age—Days	Per Cent Ash	Per Cent Solids	H_2O Retained by Cake $2^1/_2$ Min. 1000 Lb., Grams	H_2O Retained by Cake at Intersection, Grams	ΔV	Δt	$\Delta V/\Delta t$	Preparation
Calumet Imhoff Sludge, Chicago Sanitary District	235?	64.7	12.1	4.2	3.6	0.6	15	.040	Diluted original sample, 1:1
Imhoff Sludge, Decatur Sanitary District (see Figure 7-II)	255	63.8	11.0	4.0	3.5	0.5	15	.033	Diluted original sample, 1:1
Water Survey Experiment Plant (see Figure 3-C)	225	48.5	5.35	4.2	3.1	1.1	30	.037	No dilution

served, however, that there is one marked difference between the two, the branches of II coincide in a much shorter time than in I. If, instead of using the amount of water retained after 30 minutes' pressing, we use the amount retained by the cake where both branches of the curve become coincident (5.2 gm., curve I; 3.5 gm., curve II) and the time corresponding to the point of coincidence (30 minutes in curve I; 15 minutes, curve II) then we may modify Formula 1 so that it becomes applicable to all cases of comparison and yet serves for the purpose of indexing sludge ripeness. Instead of A-B (Formula 1) substitute Δv where this value is understood to mean the difference between the grams of water retained

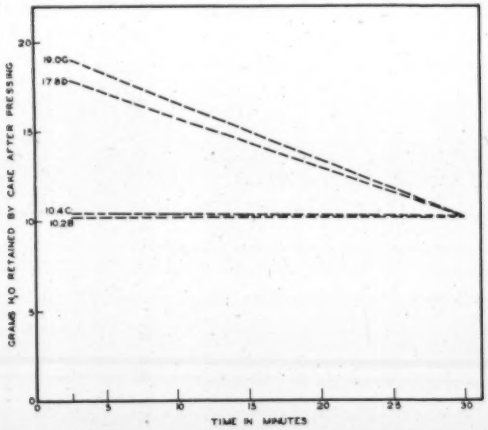

FIG. 8.—Effect of Pressure on a Sludge at Different Periods of Digestion—100 Pounds. Proven Sludges.

by cake after $2\frac{1}{2}$ minutes' pressing and the amount retained by the cake at the point where the initial and reabsorption curves are coincident. For 30 (Formula 1) we substitute the time corresponding to the intersection of the two branches of the curve. Then:

$$\frac{\Delta v}{\Delta t} \leqq \frac{1}{15} \qquad (2)$$

is still true but enables one thus to examine comparatively sludges of different solids content. It will be seen that $\frac{\Delta v}{\Delta t}$ for curves I and II of Figure 7 are equal within the limits of experimental error. These findings are

further corroborated in Table I where diluted and undiluted sludges of nearly the same age and from different districts are examined in this manner. It has been our observation, however, that no material error is introduced into exact comparisons of sludges where the per cent solids in the two samples examined do not differ by more than 2 per cent. Under these conditions, dilution is not essential.

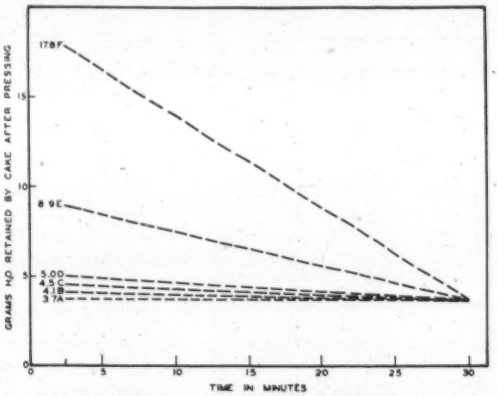

FIG. 9.—Effect of Pressure on a Sludge at Different Periods of Digestion—3000 Pounds. Proven Sludges.

To give the reader a clearer picture of the importance of this differential, it is important to emphasize that whereas the absolute values of A and B will vary with the moisture content and pressure, $\frac{\Delta v}{\Delta t}$ is for all practical purposes independent of these variables. Moreover, it may be added that this ratio for poorly digested sludges has been observed to be in the neighborhood of $^1/_4$ to $^1/_2$, whereas for very well-digested ones it ranges

TABLE II

HISTORY OF SLUDGES DETAILED IN FIGURE 8—PRESSURE 100 LB.

Age of Sludge			Grams H_2O Retained		Grams Water
Digestion	Beds	History of Sludge	$2^1/_2$ Min.	30 Min.	Reabsorbed by Cake
75 days	100 days	(B) Very old sludge from Decatur	10.2	10.2	10.3– 9.8
75 days	0 days	(C) Very good sludge from Decatur	10.4	10.2	10.3– 9.8
35 days	35 days	(D) Very poor sludge from Decatur	17.8	10.3	11.1–10.3
15 days	0 days	(G) Experimental Plant 15-day digestion, Water Survey, Urbana	19.0	10.9	11.4–10.5

from $^1/_{30}$ to $^1/_{15}$, and that sludges of the same age give nearly identical differentials.

TABLE III

HISTORY OF SLUDGES DETAILED IN FIGURE 9—PRESSURE 3000 LB.

Age of Sludge Digestion	Age of Sludge Beds	History of Sludge	Grams H_2O Retained $2^1/_2$ Min.	Grams H_2O Retained 30 Min.	Grams Water Reabsorbed by Cake
75 days	100 days	(A) Very old sludge from Decatur	3.7	3.7	3.6–3.6
75 days	10 days	(B) Very good sludge from Decatur	4.1	3.8	3.8–3.6
75 days	0 days	(C) Very good sludge from Decatur	4.5	3.8	4.0–3.8
35 days	35 days	(D) Very poor sludge from Decatur	5.0	3.8	3.9–3.8
45 days	0 days	(E) Exp. Plant 60-day set, Univ. of Illinois	8.9	4.0	3.6–3.6
15 days	0 days	(F) Exp. Plant 15-day digestion, University of Illinois	17.8	4.1	3.6–3.6

In Figures 8 and 9 along with their corresponding Tables II and III may be seen comparisons on proven sludges. Here sludges known to be poorly digested and poorly drainable are compared with those from extended periods of digestion and easily drainable types, by this method of examination. The close correlation between the age of the sludge and the water-retaining capacity is shown.

TABLE IV

SHOWING CHANGE IN AMOUNT OF WATER PRESSED OUT AT DIFFERENT PRESSURES ON 100 G. SAMPLE—TOTAL SOLIDS, 6 GRAMS

Grams Liquor Expressed	Time in Min. Pressure Was Exerted	Pressure, Lbs./Sq. In.
59.2	3	1000
77.0	10	1000
86.8	30	1000
61.8	3	3000
78.2	10	3000
87.0	30	3000
62.4	3	5000
78.2	10	5000
88.4	30	5000
65.8	3	10000
78.2	10	10000
88.8	30	10000

The data collected in Table IV brings out the fact that there is little necessity for going above 1000 lb. pressure in the examination of the sludges, because similar types of curves are obtained in all cases and there is not a wide difference in the magnitude of the amounts of water retained by the cake.

Moreover, these data illustrate another point, namely, that after a sufficient time the curves are all approaching the same asymptote. The water content may be pressed down to a certain minimum and this remains the same independent of the pressure. Investigation revealed that this minimum moisture content was approximately 25 per cent of the volume of the cake, which corresponds very closely to the volume of the voids in packing of spheres. One would therefore predict that this moisture would remain no matter how great the pressure. This fact was considered important since it proves that the failure of the cakes to reabsorb as much water as they held initially under $2^1/_2$ minutes' pressing is not a matter of hysteresis of wetting but definitely due to some deformation in the gel structure, because the water retained after 30 minutes' pressing and that reabsorbed are identical and theoretically all that could be absorbed as the voids of the cake are filled. If hysteresis operated in one case it should in the other, and since it is not in evidence on the 30-minute cakes it must not be on those pressed only for $2^1/_2$ minutes.

Inasmuch as it has not always been possible to make an immediate examination of the sludge samples as removed from the fermentation tank and these were often kept over night at 4° C. before examination, tests were carried out on the sludge before and after cooling. Nord[4] has observed a marked change in certain properties of a selected number of colloidal gels after freezing and Gortner[5] has recently observed this operation has a marked change upon dilatometer measurements of some gels, while Kuhn[6] has emphasized in a very complete review that freezing reduces water binding in colloids.

However, a 48-hour period of cooling at 4° C. did not have any observable effect upon the water retained by these sludges, as measured by pressure tests. The results of some more thorough investigations of the effect of temperature on these gels are to be found later in this paper.

Theoretical Considerations

Mathematical implications in any set of data are always numerous but there is still the question of the validity of these interpretations. Newton and Gortner[7] investigated what they have termed "bound water" in gum acacia sols. These investigators considered that they were dealing with adsorption, inasmuch as the nature of their data as well as the semi-parabolic curves obtained by its graphical representation suggested the application of Freundlich's equation. They did find this expression applicable and thus concluded that in "bound water" they were dealing with such a colloidal phenomenon.

Since we also have carried out a series of experiments that may be quite logically explained in terms of the conception of "bound water,"

and like curves have been obtained, a similar suggestion as to the application of Freundlich's equation could be made.

However, we have chosen to insert a series of operations to show how mathematical interpretations drawn from any set of data may be used to support more than one assumption.

Owing to the nature of the curves obtained in these operations and the very plausible picture of the mechanism as a capillary one it appeared to be quite sound to try to apply one of the many "Amplifications of the Law of Poiseuille,"[2] thus arriving at an explanation of our results in terms of viscous flow and with a purely mechanical picture of the operation of these gels under pressure. One of the tests for viscous flow has been applied in order to determine whether or not it is possible to explain their action upon this basis alone.

Although complete affirmation from interested authorities as to the validity of the application was not obtained, the following explanation, involving no more than the assumption of capillary action, was selected.

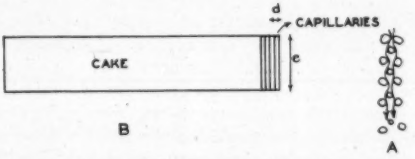

FIG. 10.—Diagram Illustrating Cake as a Capillary System.

The results of this experiment point the way to a simple explanation of the action of the sludges tested, on the basis of well-known mechanical properties of substances in a fine state of subdivision.

If it is assumed for the purpose of applying Poiseuille's equation to the flow of water from the compressed sludge cake, that the minute colloidal particles are arranged as in *A*, Figure 10, and that the water exuded simply passes through the capillary interstices between them, this simply amounts to having all the water in the capillaries.

Then the volume of the water remaining in the cake after pressing is equal to the volume of the capillaries. Then,

$$d^3 \propto V_r$$

where d is the diameter of the capillary system, and V_r is the volume of water remaining; or may equally as well be accepted as the water expressed (V_e), since $(V_t - V_r) = V_e$, which latter value we have employed in our experiments. Obviously therefore (V_t representing the total moisture content),

$$d^3 = k(V_t - V_e),$$

which is the equivalent of assuming that for fixed volumes of water exuded the diameter d of the capillaries is likewise a constant quantity.

The following development follows from Poiseuille's equation,

$$\frac{dV_e}{dt} = \frac{K\pi d^4 PgA}{128\,\nu l}$$

and is an expression for the rate of flow of water through capillary systems in terms of (V_e) volume per unit time (t); having (k) capillaries per unit area of diameter (d) and the area of the cake being (A) and thickness (l). The pressure drop through the capillaries is (P) and (ν) is the absolute viscosity, while K is a characteristic constant and π the conventional significance.

For a compressible sludge we may take account of the length of the capillaries by replacing $\left(\frac{d^4}{l}\right)$ by some function of d as d^m where m is a constant.

This equation then becomes,

$$\frac{dV_e}{dt} = cd^m P$$

If the assumption we have made previously is true, *i. e.*, if $\frac{dV_e}{dt}$ be determined for varying pressures at some constant volume Ve_c then d is likewise a constant for the previous expression and the following is true

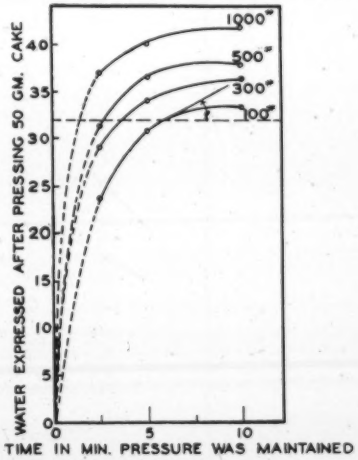

FIG. 11.—Volume—Time Curves.

$$\frac{d^2 Ve_c}{dtdP} = k''$$

which defines a linear function.

To apply this equation we obtained the data on these colloidal sludges in the following manner. At several different pressures we observed the volume of water pressed out of the cakes in time t, then $\frac{dV_e}{dt}$ was evaluated from the graphical plots, V_e, t. (*Cf.* Table V, Figure 11.) We noted $\frac{dV_e}{dt}$ at a volume, Ve_c. Assuming our original postulate to be correct,

that is $(Ve_c) = (d) = C$, a new graphical representation was made from $\frac{dV_e}{dt}$, P (*cf.* Figure 12), and a straight line was obtained.

The data presented in Tables V and VI and Figures 11 and 12 show rather conclusively that the important equations of viscous flow are applicable, provided the original assumptions are true. These conclusions are not

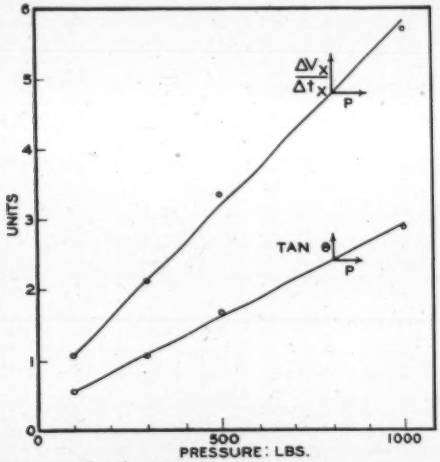

FIG. 12.—$\frac{\Delta Vx}{\Delta tx}$—$P$ diagrams.

TABLE V

DATA FOR VOLUME-TIME CURVES OF FIGURE 11

Pressure Maintained	Time Pressure Was Maintained	H_2O Expressed by 50-Gm. Cake	H_2O Retained by 50-Gm. Cake	Total Solids
100 lbs.	2½ min.	23.6 gms.	23.4 gms.	3.0 gms.
	5	31.1	15.9	3.0
	10	33.4	13.6	3.0
300 lbs.	2½	29.0	18.0	3.0
	5	34.1	12.9	3.0
	10	36.5	10.5	3.0
500 lbs.	2½	31.3	15.7	3.0
	5	36.6	10.4	3.0
	10	37.9	9.1	3.0
1000 lbs.	2½	37.0	10.0	3.0
	5	40.3	6.7	3.0
	10	42.0	5.0	3.0

TABLE VI

DATA FOR $\frac{\Delta V_x}{\Delta t_x}$, P AND TAN θ, P DIAGRAMS, FIGURE 12

Vt_c = 32 Gm.

$\frac{\Delta V_x}{\Delta t_x}$	P in Lbs.	tan θ
1.05	100	0.52
2.12	300	1.06
3.36	500	1.69
5.70	1,000	2.90

altered by assuming the maximum error in the observations. Moreover, they have been checked and still found valid. Although the correctness of the explanation may be a debatable one yet the investigators thought it best to point out this alternate set of conclusions which do not seem to require the conception of "bound" water for their interpretation.

Moreover, there are in the literature at least two experiments that contribute information of importance to these tests. Nutting[8] has calculated the pressure required to remove the molecules of water associated in silica gel, while Lenher[9] actually subjected this substance to pressures ranging from 500 to 500,000 lb. per square inch. The most generally accepted idea of the structure of silica gel is one of capillary interstices formed by spherical particles in juxtaposition. Such a formation would likewise be subject to viscous flow and at the same time the formation does not eliminate the idea of differential adsorption.

Since Nutting has shown that 12,000 lb. is sufficient pressure to remove "bound" water at a distance of 1090 molecular diameters and this decreases rapidly with increase in depth of associated water molecules; while 500,000 lb. is not enough to remove the last layers; and as Lenher's experiments show that, whatever the nature of the union in silica gel, some of the water is removed by pressures as low as 500 lb. and all of it not at a half million pounds, consequently, it is impossible to conclude anything as to the nature of the union of water in these sludge samples by the magnitude of the pressure used in these experiments.

Again, as Gortner[3] has pointed out and as cited by so many authors, the fact that aging apparently decreases the water retaining capacity of gels is explainable in terms of the conception of "bound" water. However, these workers cannot afford to overlook the fact that if the disaggregation-aggregation hypothesis of Nord[4] is accepted it is possible to explain both the action of electrolytes and the action of pressure on these sludges, thus dispensing completely with the conception of "bound" water. Moreover, the following explanation adds support to the idea of viscous flow and has found confirmation in the experimentally observed fact of Nord that the conductance of colloidal sols is inversely proportional to the square of the radii of the particles.

It is evident from our data that viscous flow may explain the semi-parabolic shape of the curves, but it apparently does not explain the difference between the curves for the raw and ripe sludge. The differences between these last named curves could be due to shrinking of the particles (loss of "bound" water) or, on the other hand, to aggregation. Shrinking should result in a smaller V_r for ripe than for raw sludges. Since V_r is the same for all sludges, ripening may be considered to consist primarily in aggregation.

If we picture the application of pressure as resulting in the movement of solid particles more closely together and away from the supernatant liquid, a qualitative analogy exists to the case of settling of particles through a liquid whereby we may examine the results of agglomeration by means of Stokes Law.

If we consider that we are dealing with capillary interstices formed by spheres in juxtaposition and that the increased rate of flow may be explained by coalescence of these spheres, thus producing a differential rate of phase separation, we may apply Stokes Law. Thus,

$$V = 2ga_1^2 \frac{(d_1 - d_2)}{9\nu}$$

where

V = maximum velocity of fall of a small sphere in a fluid,
a_1 = radius of the sphere,
ν = coefficient of viscosity,
d_1 = density of the solid,
d_2 = density of the liquid.

To investigate the effect of pressure with a change in the radius of the particle let us say,

$$V = ka_1^2 f$$

for each particle, where f is a force or pressure. Then with n particles each acted upon by f to force it through the medium the

$$\text{Total Force} = nf = F$$

Agglomerating many particles into one and applying F to the particle, then as the units in the volume (V) change from $\frac{4}{3}\pi a_1^3 n_1$ to $\frac{4}{3}\pi a_2^3 n_2$, and since volume summation is the same in either case, then

$$\frac{a_1}{a_2} = \frac{n_2^{1/3}}{n_1^{1/3}}$$

where a_1 = radius of the original particle, a_2 = radius of the final particle, n_1 number of original particles, n_2 number of final particles, which latter value will condense to 1 in this case merely for examination. Therefore,

$$a_2 = a_1 n_1^{1/3} \text{ if } n_2 \text{ is } 1.$$

The order of magnitude of the velocity change, with change in particle size as the only variable, is then observed to be,

$$V_2 = kF\,a_1^2 n_1^{2/3},$$

$$\frac{V_2}{V_1} = \frac{kF\,a_1^2 n_1^{2/3}}{kF\,a_1^2}$$

$$V_2 = V_1 n_1^{2/3}$$

This would likewise indicate that the difference in magnitude of the volume of water retained in these compressible sludges of various ages can be explained upon the basis of an aggregation hypothesis without the necessity of "bound" water conceptions.

In the succeeding discussions several different techniques are compared that would be expected to evaluate the extent of water binding in these bio-colloidal products. If any one of these methods really approximates a percentage of "bound" water then certainly the others are not indices of the same factor, and there must be some other explanation of the phenomenon.

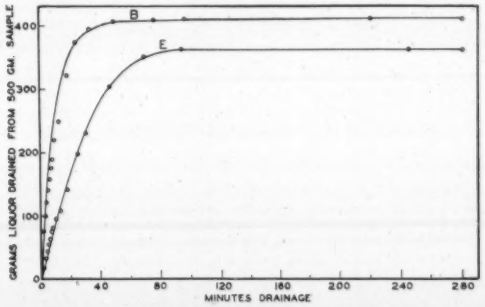

FIG. 13.—Comparison of Drainability of Decatur Sludges.

TABLE VII

COMPARISON OF CHARACTERISTICS OF SLUDGES FROM DECATUR—CF. FIGURE 13

Sludge B. Known to Be a Well-Digested and an Easily Drainable Sludge
Sludge E. Known to Be a Poorly Digested and an Easily Drainable Sludge

	B	*E*
Solids, per cent	6.88	7.6
Per cent of total water drained on 500-gm. sample in 4 hours	88.6	78.7
Length of digestion period (days)	70	35
Length of period on beds at time of examination	10	45
Grams H_2O retained by cake at 100 lb., $2^1/_2$ min	10.2	17.0
Grams H_2O retained by cake at 100 lb., 30 min	9.9	10.2
Grams H_2O retained by cake at 1000 lb., $2^1/_2$ min	4.1	5.0
Per cent ash	72.6	73.7
pH	8.0	7.8

Using samples *B* and *E*, Table VII and Figure 13, determinations of what may be colloidal, capillary or "bound" water were made by three different tests.

In the first of these, the drainability test was used,[11] accepting as "bound" or capillary water that percentage of fluid retained by the cake when samples that were run onto sand drained under gravity.

The second test employed the data derived from subjecting 50-gram samples of the sludge to 100 lb. pressure for $2^1/_2$ minutes. The grams of water retained after 30 minutes of pressing was subtracted from that held after $2^1/_2$ minutes and this difference divided by the total moisture in the sample.

The third method used was the freezing point technique of Gortner.[7]

The results of these three tests are classified in Table VIII.

It will be noted that these three methods give no correlation of the quantitative values of colloidal (?) water but it is significant that all of them do indicate a larger percentage of retained moisture in the less drainable sludge. Also it is interesting that the most extensive difference in the percentage values is indicated in the pressure test. These results indicate that "bound water" is not an entity but that the amount of water held in a gel varies by more than tenfold depending upon the method used for its determination.

Comparison of Sludge Characteristics with Increasing Age

In order again to emphasize the observation made by Buswell and Pearson[10] on the lack of correlation of various physical and chemical properties of sludges during the period of processing, several different variables have again been assembled in Table IX. These data are typical of others taken and appear in part to substantiate the observations of these authors.

It is interesting to observe some of the changes apparent in these sludge samples. Referring to the amount of the one-minute drainage from the sludges, an increase in this volume with increasing age of the sludge is noted. The same is true for ninety minutes' drainage yet if one continues to increase the drainage period a time will soon be reached where an actual reversal in the amount drained is observed with some of the older sludges. That is, if we relied upon this test and fixed the time as 24 hours, there would be no consistency whatever in the indications of age as derived from sludge drainage. For some samples drain less readily, others more so, and still others in which there is no apparent change. Moreover, there is relatively little change in the solids or ash or the other chemically determined variables. However, in case of the pressure tests there is no inconsistency in any test yet run. The water-retaining capacity always decreases with age. Furthermore, this has always been true in the course

TABLE IX

VARIATION IN CERTAIN CHARACTERISTICS OF SLUDGES WITH INCREASING AGE

Date Sludge Drawn	Volatile Acids, P.p.m.	pH	Per Cent Ash	Per Cent Solids	Drainage, Cc. from 28-Mesh Sieve, 1000-Gm. Sand, 500-Gm. Sample: 1 Min.	90 Min.	24 Hours	Alkalinity to M.O.	NH_3 Nitrogen, P. p. m.	Per Cent Settled in Centrifuge	Grams Water Retained by Cake After Pressing at 1000 Lb.: $2\frac{1}{2}$ Min.	30 Min.	Expressible H_2O/Gm. Solids
February 9	730	7.6	46.5	6.33	84	272	324	2770	454	33	17.2	3.7	
Same Sludge 60 Days After Draw	336	8.0	48.0	5.77	154	325	334	3270	611	23	8.6	3.7	0.85
February 16	463	7.8	43.6	6.14	104	308	338	2510	462	31	11.9	3.8	
Same Sludge 60 Days After Draw	186	8.7	48.0	5.14	146	331	338	3460	630	29	5.8	3.8	0.39
February 23	1152	7.5	46.5	6.33	86	276	328	2530	448	30	17.5	4.1	
Same Sludge 60 Days After Draw	264	7.3	49.0	6.05	114	292	317	3480	630	30	14.6	4.1	1.73
March 1	288	7.4	45.2	6.2	100	295	330	2670	476	33	14.6	4.1	
Same Sludge 60 Days After Draw	264	7.8	48.5	5.73	122	307	335	3230	600	26	7.8	4.1	0.65

of four hundred tests on different sludges. Some observations on the B. O. D. test are listed in the next communication.

Another experiment performed in order to try to correlate properties of a more uniform material with the extent of hydration or water-retaining capacity was the setting up of a pure cellulose fermentation tank (7 liters) in which an active bacterial flora was gradually built up by slowly increasing the feed until 75 grams of pure cellulose was added in one batch. The daily gas production was noted and the water-retaining capacity of sludge cakes therefrom was determined from time to time to see if there was an increase in the degree of hydration with digestion. Although digestion proceeded normally and the tank did not "go sour" the sludge never displayed any of the properties evidenced in the sewage sludge. Here was a case then in which the material dried as readily as ordinary paper, contained a high bacterial concentration and would be expected to have a high B. O. D., yet the pressure test showed absence of colloidal or capillary properties. This material might be said to indicate that the dewatering is no way associated with the living organisms or they may closely parallel in their life period that of the colloids but have no influence upon the dewatering.

TABLE VIII

COMPARISON OF "BOUND" WATER DETERMINATIONS

	Sludges B	Sludges E
Per cent "bound" water as determined by drainability	13.4	21.3
Per cent "bound" water as determined by pressure	1.0	15.7
Per cent "bound" water as determined by freezing-point method	2.7	5.2

Conclusions

(1) The rate at which water was expressed from sludge varied with ripeness.

(2) The amount of water reabsorbed by dried press cake was independent of ripeness of the sludge from which it was obtained.

(3) The value of $\frac{dV}{dt}$ approached a minimum which was practically independent of ripeness of sludge.

(4) $\frac{dV}{dt}$ for ripe sludges is much smaller than for unripe sludges.

(5) The form of the curves for amounts of water retained *vs.* time can be explained from Poiseuille's formula without involving the conception of "bound water."

(6) The change in the value of $\frac{dV}{dt}$ with aging can be explained by assuming aggregation of particles or by shrinkage of particles due to loss of "bound water."

(7) Since various methods for evaluating the amount "bound water" give widely varying results, we prefer the aggregation theory for explaining the mechanism of sludge ripening, at least for the present.

(8) The variations in several physical and chemical properties in aging of sludge have been studied, while at the same time following the change in the action of the samples under pressure.

Acknowledgment

The authors wish to acknowledge the assistance of the Chemical Foundation in providing funds for this project. They also wish to express their thanks to Dr. F. W. Mohlman, Director of Laboratories of the Sanitary District of Chicago, to Dr. W. D. Hatfield of Decatur for assistance in the selection and collecting of sludge samples, and to Dr. S. S. Kistler of this laboratory for his suggestions in connection with the applications on viscous flow.

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Digesting Sludge at 37° C.

BY C. E. KEEFER AND HERMAN KRATZ

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During the past six or eight years considerable study has been given to the effect of heat on the digestion of sewage solids. Sludges have been digested over a wide range of temperatures both in the laboratory and in full scale installations up to temperatures as high as 70° C. From the studies and observations made thus far it is generally believed that the optimum temperature for digestion is at about 26° to 28° C. except when the digestion is thermophilic. Then the optimum temperature is about 55° to 60° C. In spite of the numerous experiments which have been made at various temperatures, little work has been done using temperatures at about 37° C.

Sierp, Blunk and Eddy have studied the relationship between gas production and the temperature of digesting sludge. In these studies neither was the optimum temperature of digestion determined nor was the gas production recorded for temperatures over 25° C. Rudolfs[1] in 1927 digested sludge in the laboratory at five different temperatures, varying from 10° to 35° C. Between these temperature ranges he found the optimum for digestion to be at about 27° to 28° C. His work indicated that sludge kept at 29° C. took 54 days to digest as compared with a digestion time of 108 days for sludge kept at 35° C. In a later group of experiments, where he[2] digested sludge at 37°, 45° and 55° C., he stated that the digestion at 37° C. "was beyond the optimum for non-thermophilic digestion." A group of experiments at Manchester,[3] England, also indicated that digestion was more rapid at 27° F. than at 38° F. Taylor[4] in reporting on the operation of a separate sludge digestion tank at Rome, N. Y., stated that when the temperature in the tank was above 32° F., conditions were not favorable for gas production and that the optimum temperature appeared to be between 26° and 29° C.

In order to obtain additional information regarding the digestion of sludge at 37° C. experiments were conducted at Baltimore to determine the difference in time required to digest sludge at 28° and 37° C. During these tests the sludge kept at 37° C. required from 5 to 10 days less time to digest than the material incubated at 28° C. At the two temperatures, however, the methane and the total gas production were about the same.

Description of Experiments

Three series of experiments were made. The raw sludge used during each series of tests was obtained from one of the preliminary settling tanks at the Baltimore sewage works. The material was usually five or six days

old with a pH value varying from 4.8 to 5.0. The sludge used for seeding was approximately 50 days old, and was well digested. The two sludges were mixed in the ratio of two parts by weight of raw material to one part of ripe sludge, the relative proportions being based on the volatile solids present. The mixture was then divided into four parts, two of which were digested at 28° ± 1° C. and the other two at 37° ± 1° C. The characteristics of the sludges used during the three sets of experiments are given in the accompanying table. The materials were digested in 5-gal. bottles.

CHARACTERISTICS OF SLUDGES DIGESTED

	Raw Sludge	Digested Sludge	At Beginning of Test 2 Parts Raw Sludge 1 Part Digested Sludge	At End of Test 28° C.	At End of Test 37° C.
Test No. 1					
Solids, per cent	8.1	6.6	7.5	5.5	5.4
Volatile matter, per cent	80.9	55.9	66.8	54.0	53.5
Ether soluble matter, per cent	27.3	6.5	24.0	6.4	6.9
pH	4.8	7.0	6.5	7.5	7.7
Test No. 2					
Solids, per cent	9.3	9.2	9.5	7.1	6.8
Volatile matter, per cent	78.0	57.6	65.0	52.8	51.3
Ether soluble matter, per cent	38.2	6.2	17.0	6.5	7.4
pH	5.0	7.0	6.6	7.3	7.4
Test No. 3					
Solids, per cent	11.9	5.2	8.0	5.4	5.3
Volatile matter, per cent	78.5	54.8	69.3	53.1	52.1
Ether soluble matter, per cent	31.2	8.2	22.1	9.9	9.2
pH	4.9	7.0	6.5	7.3	7.5

Ten pounds of the mixture was put in each bottle during Tests 1 and 2 and 12 pounds during Test 3. In each instance lime was added to the sludge to bring the pH value up to 7.0 to 7.2. The quantities of gas generated by the sludges were measured at least twice a week and sometimes daily, depending upon the volume produced. At the same time analyses of the gas were made. The quantity of gas produced in each instance has been used as a measure to indicate the extent to which digestion proceeded. Gas volumes have been reduced to 0° C. at a pressure of 760 mm. of mercury.

Results

The results of the investigation are given in Figures 1, 2 and 3. Each of the curves is an average of two sets of observations. The results obtained during Tests 1 and 2 are practically identical. In each case the sludge kept at 37° C. digested slightly more rapidly than that at 28° C. The total gas production was about 800 cc. per gram of fresh dry volatile solids, and the quantity of methane was about 550 cc. per gram.

Test No. 3 was different from the other two tests in that the digestion process at the beginning of the experiment was retarded for some unknown reason. During the early part of the test the sludge at 28° C. digested

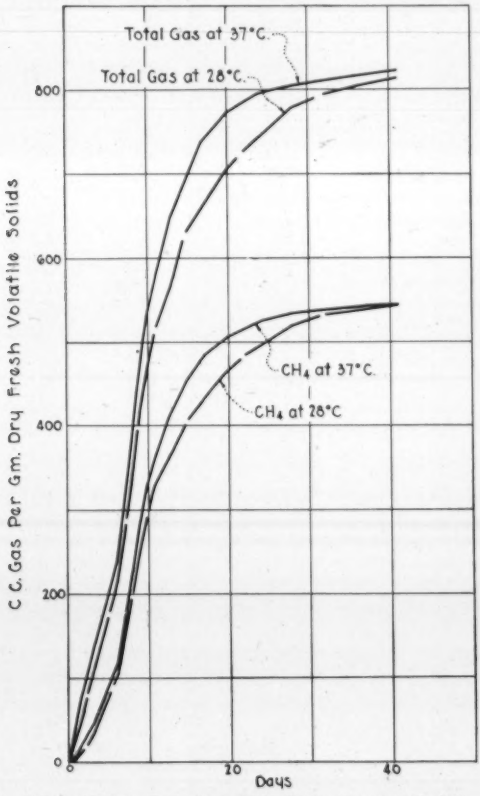

FIG. 1.—Test 1—Gas Produced from Sludges Incubated at 28° and 37° C.

more rapidly than that at 37° C. This latter material, however, decomposed more rapidly during the latter part of the observations.

The results of the studies indicate that so far as Baltimore sludge is

concerned solids digest slightly more rapidly at 37° C. than at 27° C. The speeding up of the process, however, at the higher temperature is not marked.

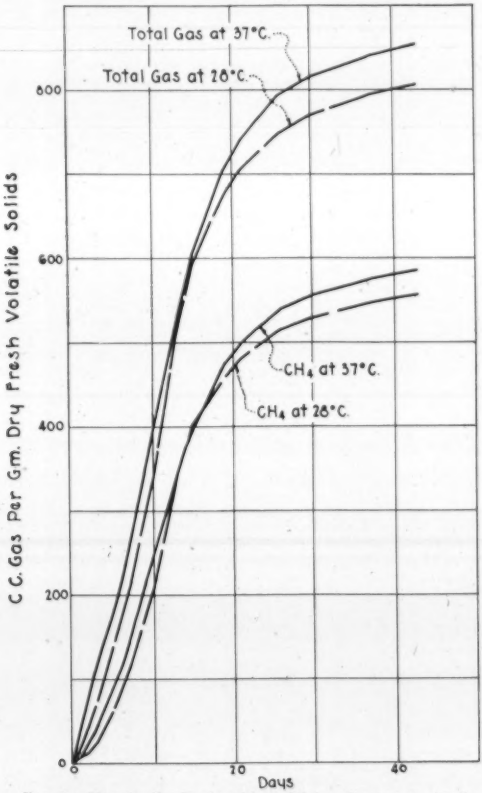

FIG. 2.—Test 2—Gas Produced from Sludges Incubated at 28° and 37° C.

The Baltimore sewage works is under the general supervision of B. L. Crozier, chief engineer, Department of Public Works, and George E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due to J. Bushman, who assisted in the laboratory work.

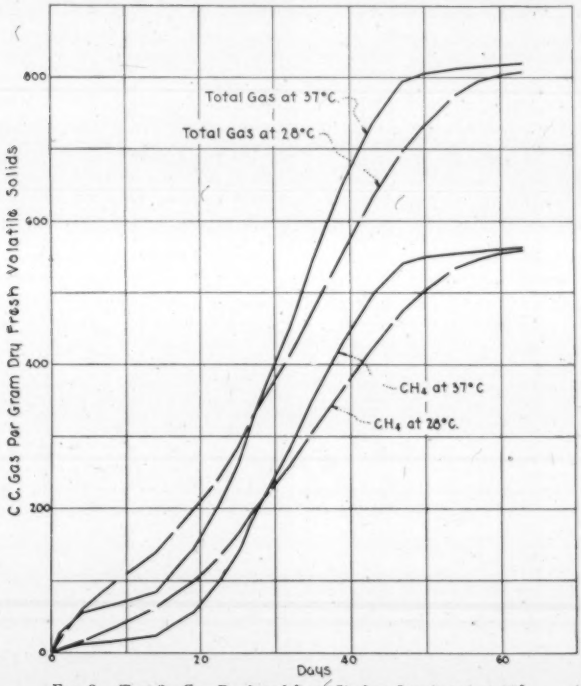

FIG. 3.—Test 3—Gas Produced from Sludges Incubated at 28° and 37° C.

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Discussion of Paper by Gleason and Loonam "The Development of a Chemical Process for Treatment of Sewage"*

BY WILLEM RUDOLFS

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Chemical treatment of sewage is one of the oldest methods of artificial purification. Since the reports of the Royal Commissions in England were published we have had recurring waves of interest in chemical precipitation. It is not necessary to refer to the numerous processes tried (including lime, iron salts, aluminum salts, Miles acid process, electrolytic-lime process and a host of others) except for the fact that basically the same group of chemicals are appealing again and again to different groups of investigators.

Probably the main reasons why chemists and engineers are interested in chemical precipitation, and why there is at present again such a promise in favor of non-biological treatment, are:

(1) The trend of greater mechanization of equipment and the fact that biological processes are becoming more and more complicated, requiring increased skill and scientific control.

(2) That most engineers feel more at home with non-biological processes which allow them (assumedly) to make definite calculations concerning the construction and operation.

(3) That there is more commercial interest in promoting mechanical and chemical processes than biological.

Thus far all chemical processes have had disadvantages sufficiently great (less effective, more costly, too large volumes of sludge produced, cumbersome in operation, etc.) to favor biological treatment for large installations as well as for small. If, however, a process is developed which has an effectiveness approximating that, or better than that, of biological treatment, a process that does not produce odor or other nuisances, is less costly in building and operation and does not leave on our hands an excess quantity of residue to handle, we have something of interest to all employed in the field.

On the surface, it appears that the Guggenheim process comes nearer to the ideal and goes further than any chemical process proposed. The results obtained with the sewage treated are unusually good. As a matter of fact so good that one is inclined to ask whether, in the case of the low B. O. D.'s, for instance, interfering substances were present in the effluent

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and whether the samples were re-inoculated. If pH values had been given we could possibly make a guess off-hand.

The speaker was impressed with the rather low ammonia content of the sewage, 12 to 14 p. p. m., in the raw sewage in connection with the average suspended solids. The ammonia and B. O. D. would seem to indicate a rather fresh sewage, which is comparatively easy to handle. Nevertheless, the quantities of ferric sulphate and CaO required are rather high.

The authors state that one of the most important advantages over other types of treatment giving equal purification is simplicity of operation. The first impression gained by looking at the flow sheet is decidedly opposite. The numerous tanks and filters would look rather complicated for a small plant. Most of us are particularly interested in small plants because there are so many more than large plants treating from 50 to 100 m. g. d. The number of plants in this country treating 50 m. g. d. or more can almost be counted on the fingers of one hand, whereas in New Jersey alone there are more than 375 plants treating individually less than 10 m. g. d. It would therefore be of interest to hear from the author how many operators would be required, say, at a plant treating 5 m. g. d. This brings up also the question of cost. The estimates made compare with very large plants like those in Chicago, Milwaukee, etc. Have the authors made any estimates for smaller plants? Or may we assume that the cost for smaller plants is in proportion?

The system as provided is a very complete layout and naturally the question arises whether for small plants recovery of ferric sulphate with H_2SO_4 would pay. If this part was left out, would the reduction in attention pay for the increased cost of the chemical to be used? If not, how much greater would the cost of operation be? The salt used for regeneration of the zeolite filters cannot be discharged into the stream and must be recovered. What about the additional layout and cost for small plants?

The plant would be of especial interest in places where high purification is required and where low volumes of dilution water are available. At many places, the volume of diluting water is sufficient to carry some load. If the zeolite part was left out from the plant, I understand that the suspended solids removed would amount to 90 per cent and the B. O. D. reductions to 60 per cent. These figures are not extraordinarily high for a chemical precipitation process. If we assume that a town with a flow of 5 to 10 m. g. d. would want to make use of the chemical precipitation process up to the zeolite softeners and without ferrous sulphate recovery, but with sewage filtration and incineration, could the authors give us a rough estimate of the cost of building and operation?

In the body of the paper the authors make some statements which are

of particular interest to us from a theoretical standpoint. They say that it is known that colloids present in sewage "exercise osmotic pressure against the medium which carries them (*e. g.*, the water) and that the reduction of the osmotic pressure is a measure of the efficiency of coagulation of these particles." The first part of this statement is probably a general hypothesis not based upon actual investigation with sewage, because we find that upon dialysis of sewage apparently the colloids themselves do not exercise the osmotic pressure, but that the osmotic pressure is due to the salts adsorbed on the colloids. We have been interested in sewage coagulation and sludge dewatering for some time and believe that fundamental investigations will lead us to a better understanding and eventually to less costly treatment. In this respect I was also much interested in the fact that the authors are convinced that the sulphate radical unquestionably aids in breaking down the complex colloids to simpler ones, including amino-acids. This is of fundamental interest and we would like to know more about the details of this definite conclusion. Is it the authors' opinion that ferric sulphate is more effective than ferric chloride in respect to breaking down complex compounds?

The authors have presented an exceedingly interesting paper, one of many, I venture to say, which will be presented during the next few years. I believe that the presentation and discussion of such papers will do much to stimulate the interest of sanitary engineers and chemists.

In conclusion, I wish to mention one more point of importance and advantages of this system over others—particularly biological plants producing highly purified effluents—the reduction of ammonia and other soluble material in the effluent. There are several places where high purification is required and the dilution water insufficient, with the result that algae growths in the receiving streams become abundant and cause considerable nuisance. The ammonia, nitrates and carbonates in the effluent are undoubtedly important factors in the elimination of these growths. Keeping them out of the stream should prevent troubles and nuisances.

Correction

In the paper by Rudolfs and Miles, "Heat Losses from Sludge Digestion Tanks," in the January, 1933, issue of This Journal, the volume of circulated heating water used during the first period, as reported at the bottom of page 24, should be 1250 cu. ft. per day, and not 1620.

Plant Operation

Chemical Treatment of Sludge to Facilitate Disposal*

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The use of chemicals in sewage-treatment practice is not new. We find many interesting accounts of their application in the days when chemical precipitation was in use. One of the first attempts to make use of the principles involved was in the so-called A, B, C process, in which sludge was deodorized and precipitated by the addition to the sewage of alum, charcoal or some other material and clay. This was one of the earliest satisfactory methods of clarification by chemical precipitation. Later sulphate of alumina, iron sulphate and lime, or lime alone came into use at many treatment plants.

In the United States only a few municipal sewage treatment plants still use chemical precipitation, but increased use of the process has occurred in the field of industrial waste treatment, and more recently a revival of the process in the municipal field. The process, as an improved means of clarification, has always been inherently sound but has been attended with the problem of economically disposing of the large quantities of sludge produced. With the development of modern sludge disposal equipment, including sludge filters, driers and incinerators, it is believed that the process may again command the attention of designing engineers. It is also possible that moderate doses of chemical precipitants will not interfere seriously with Imhoff tank or separate sludge-digestion practice. More definite information, however, concerning this latter subject is necessary before practical application and in any event careful technical control will be required so as to combat a common fallacy that "if a little is good more is better." There has been for a long time a demand for a dependable and economical process providing an intermediate degree of treatment between plain settling and filtration or activated-sludge treatment; apparently chemical precipitation is able to provide this intermediate degree of treatment.

The use of chemicals, particularly lime, to facilitate and control digestion has been discussed many times and many articles on the subject have been published. The literature, however, is not so complete with respect to

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information concerning the application of chemicals to facilitate the drying and disposal of sludge.

The primary concern in most treatment plants is the removal of organic solids, either settleable, suspended, colloidal or soluble. A secondary consideration is the disposal of these removed solids. These two problems are inter-related and the latter is usually the more troublesome in the operation of the plant.

There are three main fields for the use of sludge conditioning agents: (1) the treatment of excess activated sludge, either before filtering or before drying on sand beds; (2) the use of chemicals to condition digested or even raw sludges to accelerate draining and drying, where sludge disposal facilities are limited; and (3) the treatment of poorly digested sludge to reduce or prevent odor nuisances and also to increase drainability and permit quick disposal. (The rates of dosage should preferably be expressed in per cent or pounds per hundred pounds of dry solids, but in this paper rates are given in pounds per thousand gallons as the solid contents of the sludges are frequently unknown.)

Conditioning Activated Sludge

Referring first to the disposal of excess sludge from activated-sludge plants, many instances are found of the use of chemicals for conditioning the sludge before filtering or applying to sludge drying beds. Such treatment is usually considered essential if the disposal of the sludge is to be carried out economically and without nuisance as an alternative to digestion and drying on sand beds. Fresh sludge produced by the activated-sludge process has a high moisture content, low specific gravity, is highly putrescible, has poor drainability and is difficult to handle on filters or drying beds if not treated within a few hours after removal from the final settling tanks.

Some attempts have been made to simulate the "gas lifting" effect found in well digested Imhoff or separate digestion tank sludge. This process is known as the "flotation" process and consists of the addition of soda ash and sulphuric acid with application of heat to evolve bubbles of carbon dioxide which would lift the solids to the top and allow the liquid to drain off through a sand bed or be readily separated in a mechanical filter. At Houston, Fugate and Stanley[1] obtained the best results with 105 pounds of soda ash and 260 pounds of sulphuric acid per ton of dry product at a temperature of 45° C. The resulting sludge had a moisture content of 97 per cent, which showed the process to be impractical at that plant. Attempts were then made to filter the sludge directly and also after acidifying with sulphuric acid or sulphur dioxide gas. With plate and frame filter presses, the operating cost was about $35.00 per ton. A standard wet machine, as used in the paper pulp industry, was then installed but

certain mechanical difficulties required modifications and development of a new machine, which was tried and finally abandoned. A vacuum filter was next used and aluminum sulphate or ferric salts used as conditioning agents. This proved successful so that a large installation was installed in 1928. The optimum filtration of the sludge was found to be at pH 4.8 for aluminum sulphate, and 5.4 for ferric chloride. A sludge of 80 to 82 per cent moisture content was produced.

In 1926 a process was tried at Houston consisting of treatment of the sludge with a conditioner and running the sludge to drying beds for partial drying, using racks or heat dryers for final drying. However, there were bad odors before the sludge could be removed from the beds, so this process was abandoned. The conclusions drawn from these experiences indicated that sulphuric acid and sulphur dioxide gave indifferent results, while alum and chlorinated copperas were efficient, the choice being a matter of cost.

The foregoing illustrates in a general way a few of the factors involved in treating activated sludge at one plant. Cramer[2] at Milwaukee reported on the use of sulphuric acid, alum, chlorinated copperas and ferric chloride, and found them increasingly efficient in the order named. Mohlman[3] showed that 4 to 10 lb. of aluminum sulphate was necessary per 1000 gallons of 98.5 per cent moisture sludge. The alum treatment was more effective than treating with sulphuric acid.

The de-watering of activated sludge, and in fact any sludge, varies with the temperature, being more rapid at higher temperatures. At Milwaukee it was found that it would take about 20 times as long to de-water sludge produced from sewage at 45° F. as it did sludge from sewage at 70° F. It was further found that the use of alum and sulphuric acid, together with heating to a temperature of 180° F., increased the filtering rate 40 times the normal rate.

At Charlotte, North Carolina[4] ferric chloride or alum have been used for sludge conditioning before filtering on Oliver vacuum filters. The dosage to obtain good results was 8 lb. ferric chloride per 1000 gallons as compared with 10 to 14 lb. alum per 1000 gallons. It is stated that ferric chloride is efficient at all times, producing a sludge having a moisture content of 80 per cent. At Gastonia, North Carolina, ferric chloride at a rate of 7.5 lb. per 1000 gallons has been used.

Mohlman and Palmer[5] at the Calumet sewage treatment plant of the Sanitary District of Chicago, found that the use of chlorinated copperas for coagulation of activated sludge was very effective. Various coagulants were tried, including sulphuric acid, heat, alum, dicalcium phosphate, bone ash, sulphur dioxide and filter cel. The sludge applied had a moisture content of 96 to 97½ per cent. During 1924, 7 to 11 lb. of alum per 1000 gallons were used, while in 1925 it was necessary to use 17 lb.

per 1000 gallons to obtain satisfactory results. Ferric salts were found to be more effective, the best results being obtained with ferric chloride. The cost at that time for ferric chloride was prohibitive so that chlorinated copperas was finally decided on as the best coagulant.

Information obtained from the same article by Mohlman and Palmer indicates that laboratory experiments carried out by Dallyn and DeLaporte[6] showed that ferric chloride was the most effective coagulant for activated sludge. Ferric chloride was used in a test on coagulation of activated sludge applied to the Oliver filters at Pasadena in May, 1925. The same effective coagulation was noted as was obtained at Chicago.

Tests made by Ardern[7] at Manchester, England, on an Oliver filter using activated sludge from the Dayyhulme plant showed that ferric chloride produced higher yields than alum.

At Tenafly, New Jersey, where the excess activated sludge was originally intended to be dried without chemical treatment on glass covered sludge-drying beds, a 5000 gallon steel tank has been erected in which the sludge is treated with about 18 lb. of alum per 1000 gallons before applying to the beds. The treatment with alum has been found to be practical and effective in readily drying the sludge.

Conditioning Digested and Raw Sludges

Lime was formerly used to accelerate drying and draining of sludge. At Providence, R. I., the sludge from the chemical precipitation tanks was treated with lime, filtered in plate and frame filters, de-watered to about 75 per cent moisture content, after which the material was barged to sea and dumped. At Worcester, Mass., lime precipitated sludge was filtered in plate filters until 1917 when, because of labor shortage, this process was abandoned. Winston-Salem, N. C., and Dearborn, Mich., are filtering raw sludges heavily treated with chemicals.

Rudolfs, Setter and Baumgartner[8] have described the effects of iron compounds on sedimentation, digestion and ripe sludge conditioning. In reference to ripe sludge conditioning, filtration through filter papers and field experiments were carried out, using ferric chloride as the conditioning agent. Sludge of 92.7 per cent moisture content was treated at rates of 0.5 to 2.0 lb. per cubic yard, corresponding to about 2.5 to 10 pounds per 1000 gallons. It was found that comparatively small quantities of ferric chloride gave rapid increase in drainage. For example, the same percentage removal of water was obtained in $1^1/_4$ minutes with 2 lb. ferric chloride per cubic yard, as compared with 14 minutes for untreated sludge. The results of field experiments showed further the advantages of the addition of chemical coagulants to increase drainability of the sludge.

The action of ferric chloride on sludge in coagulation is practically

instantaneous. Therefore, the chemical may be added as the sludge is being drawn to the drying bed, with only sufficient mixing to insure distribution of the chemical. The optimum dosage will vary with different sludges, depending on their condition and solid content.

Goudey of Los Angeles[9] is carrying out considerable experimental work on the use of chemicals for conditioning digested, activated and raw sludge for filtration.

In the Annual Report of the Department of Sewage Disposal of the New Jersey Agricultural Experiment Station, 1928–1929, Baumgartner reports on the effect of certain chemicals on the vacuum filtration and also gravity drying of ripe sludge. Ferric chloride, ferric aluminum sulphate, sodium aluminate and a mixture of sodium aluminate and caustic soda were used as conditioning agents. Ferric chloride proved to be the most effective, both for filtration and accelerated drying on the sludge bed.

In this same publication Fischer in "Notes on Drying Fresh Sewage Solids" gives the results of laboratory and field tests, using chemicals and heat as conditioning agents. Alum, lime and mixtures of alum and lime were used in sludge applied to drying beds. It was concluded that drying of fresh solids in the open was not feasible on account of poor drainage and odors.

Van der Meulen and Smith[10] found that the use of alum accelerated the rate of filtering of an Imhoff tank sludge. The dosage was at a rate of about 35 lb. per 1000 gallons and an 80 per cent moisture sludge could be obtained in about 4 minutes.

Rudolfs, Downes and Campbell[11] showed that the draining time of ripe sludge on sand beds could be decreased 50 per cent by the addition of 15 lb. of alum per 1000 gallons of sludge.

At Rockville Centre, N. Y., Kneale reports the experimental use of alum to accelerate the drying of sludge from separate sludge-digestion tanks digesting both fresh solids and excess activated sludge. The dose was about three lb. per 1000 gallons of 96 per cent moisture sludge, applied in solution form from a barrel. This dosage reduced the drying time from 30 days to 22 days when the sludge was drawn to a depth of 12 inches in glass-covered beds. On open beds hydrated lime was found to be beneficial in the drying process, when sprinkled over sludge 4 inches deep at a rate of about 5 lb. per 1000 gallons. This sludge was ready to remove in four days with about 70 per cent moisture content.

At Greenwich, Conn., a unique method of sludge treatment is employed. Instead of applying the chemical to the sludge, chloride of lime is sprinkled over the surface of the sludge bed at a rate of about 50 lb. per 1000 square feet. The sludge is then drawn on the bed to a depth of about 6 inches. Accelerated drying and odor control is indicated.

Experiments carried out by Downes at Plainfield, and mentioned by

Fales at the 1926 Conference of Sewage Plant Operators in Pennsylvania, show that relatively small amounts of sulphate of alumina or alum greatly improved the drying quality of sludge at Plainfield which, without treatment, did not drain or dry readily. Where the sludge was dense and of good quality, as at Fitchburg, very little advantage was gained through the use of alum.

Downes found that the use of about 7 lb. of alum per 1000 gallons applied to digested sludge as it entered the drying beds made possible an increase of from 6 dryings per bed without treatment to 11 dryings with treatment during a seven-month period.

Mention may be made of another type of sludge conditioning which is of interest. Babbitt at the University of Illinois found that the freezing of sludge altered the draining qualities of the sludge, allowing the entrained water to separate very quickly after thawing. He also suggested that it is feasible to remove the sludge from the drying beds in cold weather while still in a frozen condition. This practice has been used to some extent by Cohn at Schenectady.

Treating Poorly Digested Sludge

The third field for the use of chemicals in treating sludge from a sewage treatment plant is in reference to the prevention or control of odors and the acceleration of drying of sludge which is in poor condition. This is probably the most important field from the point of view of the largest number of operators in the State. Whenever an accumulation of acid sludge has built up in an Imhoff tank or a separate sludge-digestion tank, advice is frequently given to empty the tank and start over again. This is usually the most economical way of correcting unsatisfactory digeston conditions. It may be said that the sludge should never have been permitted to reach such a state, but the fact is that "it happens in the best of families." The problem then arises as to what to do with the sludge to be removed. Such sludge is usually acid, odorous and has very poor drainability. It thus becomes a serious problem to dispose of this material readily and without nuisance.

For odor control there is an advantage in using a chemical that will partially disinfect the sludge and also react with the odor-producing substances. Chloride of lime is such a chemical which has this faculty. Gaseous chlorine is a recognized deodorizing agent in that it combines with the odor-producing compounds to form inodorous or unobjectionable substances. The possible chlorinous or medicinal odor produced is far less objectionable than the typical hydrogen sulphide odor.

In Cassel, Germany,[12] over twenty years ago lime was used to prevent odor nuisance and fly breeding in sludge removed from settling or septic tanks. The rate of application was approximately 6.8 lb. per cubic yard

or 34 lb. per 1000 gallons. The fertilizing quality of the sludge was reduced but this is not regarded as a matter of serious concern. At Worcester where lime precipitated (about 1000 lb. per million gallons sewage) sludge was de-watered by filter presses, the sludge cake produced was used locally by farmers for fertilizing purposes.

It is interesting to note that twenty years ago manufactured deodorants were advocated. A by-product of the tar industry called "facilol," a brownish light oil with phenolic characteristics, was sprayed over the surface of the sludge preventing putrefaction and fly propagation.

At Huntington, N. Y., where the digestion tank accumulated a quantity of sludge in acid condition, various methods were tried to effect deodorizing and rapid drying of the sludge applied to glass-covered sludge drying beds. The glass-covered beds were unable to confine the odors to the plant, and nuisance complaints developed when untreated sludge was drawn. Experiments were carried out, using ozonators to deodorize the sludge enclosures but such experiments proved unsuccessful. After considerable experimentation with alum, ferric chloride, lime and chloride of lime, it was found that chloride of lime applied to the sludge would give satisfactory results. Therefore, a barrel was set up in which 100 to 150 pounds of chloride of lime were dissolved and added to the sludge in a trough as it was being drawn to the sludge drying beds. Sludge was drawn to a depth of about 6 inches and in 7 days was ready to remove in an inoffensive condition. The rate of dosage at this plant was 20 to 30 pounds per 1000 gallons. After drawing, the surface of the bed was further sprinkled with a small amount of chloride of lime and no further nuisance conditions have developed.

At Port Chester, N. Y., where because of limited digestion capacity the sludge is in slightly acid condition, Mowbray used 35 pounds of chloride of lime to 3000 square feet of sludge drawn 9 inches deep. At this plant the chloride of lime was applied dry to the sludge in a manhole on the sludge line before entering the bed. It is reported that this low rate of dosage (2 lb. per 1000 gallons) reduced odors appreciably.

At Fairport, N. Y., where sludge digestion has until recently been seriously affected by industrial wastes, Cary has spread dry lime over the sludge on the drying beds a day or two after drawing to control odors. The dose used is 100 pounds to 1800 square feet, or if the sludge is drawn 6 inches deep the rate would be about 15 pounds for 1000 gallons. Cary has also developed an effective means of treating the secondary tank sludge, which is a source of considerable odor nuisance when drawn and is difficult to de-water and dry on the sand beds. In July, 1932, he placed 75 pounds of chloride of lime in a loosely knit sack and dissolved it in the secondary tank by drawing it through the tank liquor. Sludge was removed 48 hours later and it was found to have little objectionable odor

and dried much faster than without treatment. The experiment was repeated with 50 pounds of chloride of lime in September with similar results.

Summary

There has been considerable unpublished work carried out within the past few years on the use of chemicals in sewage treatment, including sludge conditioning. It is hoped that this discussion will stimulate research and make such information readily available to the profession. Within the next few years there will undoubtedly be a considerable trend toward the increased use of chemicals in sewage-treatment practice, particularly for development of mechanical chemical treatment processes, and for sludge conditioning both for digestion and disposal.

As a result of numerous satisfactory experiences, the value of chemicals in making possible economical and convenient methods of conditioning sludge for disposal is becoming appreciated. Among the chemicals most frequently used are lime, chloride of lime, alum, chlorinated copperas and ferric chloride. Alum, chlorinated copperas and ferric chloride appear to have valuable properties in coagulating and thereby aiding in the dewatering of sludge. Lime and chloride of lime are of special value in deodorizing and conditioning sludge in a poorly digested condition.

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Approach to City Saved by Sewage Works Design, Construction and Operation of the Saranac Lake Plant*

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The principal approach to Saranac Lake from the north follows the Saranac River as it runs at the foot of the slope on which this highway is constructed. The raw sewage from the village was formerly discharged into the river near the Pine Street Bridge and the sewage pollution was plainly visible from the highway and caused a distinct nuisance during the summer months. This condition was augmented by a second raw sewage discharge, that from the Trudeau Sanitarium, located just north of the village proper. The usual condition resulting from the discharge of crude sewage was aggravated by the characteristics of the sewage and those of the river. The Saranac River at the point of sewage discharge is shallow and wide, and has a sluggish and circuitous flow, while the bed of the river was chocked with river grasses. The sewage from both the village and the sanitarium is a domestic sewage with an unusually heavy sludge content, and soaps and greases from extensive laundry wastes. The resulting river condition was neither suited to an approach to a municipality, nor to the standards of a widely known health and sports resort.

However, a few days after the sewage had been diverted to the trunk sewer extension and the disposal plant, the above situation cleared itself with surprising rapidity; the natural clarity of the water was restored and only a small deposit of sludge was noted in front of the outfall sewer. Later on, the river grasses disappeared and the shore line condition corrected itself.

General Description

The sewage collecting system of Saranac Lake was built many years ago. The construction of this system involved some work in quick-sand and the main sewers follow the Saranac River and for some periods of the year are below the river levels. The new construction includes a trunk sewer extension of about 1600 feet to a new pumping station. From this pumping station, the new trunk sewer delivers the sewage by gravity to a disposal works about 5000 feet further down the river. The disposal works consist of an office building, three shallow settling tanks, two sludge

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tanks, a sludge bed area and a new submerged outfall sewer to the Saranac River.

Type of Sewage Works

The Saranac River is not used for a water supply below the Village of Saranac Lake. From investigations at the Saranac Lake laboratories and elsewhere, it was assumed that tuberculosis is not distinctively a water borne disease and consequently the type of plant required for the situation resolved itself into one that would prevent nuisance and not overtax the Saranac River with oxygen demand. The watershed of the Saranac River at the Village of Saranac Lake is about 185 square miles. Local gaugings of the river flow were not available but the gaugings taken at Plattsburg for a period of years were pro-rated for the local watershed. The Plattsburg readings are, however, affected by power storage, especially on Sundays, and are not fairly pro-rotated for the local shed. After working over available data it was decided that a minimum weekly flow of not less than 100 second feet would obtain in a dry year. The average flow of the Saranac River may be safely taken at over 200 second feet. The flow of the Saranac River at Saranac Lake is partially controlled at a power dam serving the pumping station of the village and a hydro-electric station of the Paul Smith Electric System.

For purposes of design, the situation was analyzed on the basis of the 100 second feet flow. For northern water temperatures, the dissolved oxygen content of the Saranac River water was taken at 75 pounds per million gallons or 4875 pounds per day for 100 second feet, and 9750 pounds per day for the average river flow. With preliminary treatment, a B. O. D. factor of 0.14 pound per capita per day seemed justified and 1540 pounds of oxygen represent the settled sewage demand from a population of 11,000. For the future demands of 20,000 people, the above B. O. D. figure will be increased to 2800 pounds per day. With the existing population of 11,000 people, the oxygen demand is only one-third of the available oxygen for minimum weekly flows and one-sixth for the average flows. For a future population in 1980, optimistically taken at 20,000 people, the oxygen demand would be a little more than one-half of the oxygen supply for minimum weekly river flows and slightly more than one-quarter of the available supply for average flows.

On the basis of the above oxygen figures, it was decided that preliminary sedimentation with separate sludge digestion would adequately avoid overtaxing the Saranac River and prevent nuisance. The location selected for the sewage works site was at a point away from any probable river front development and the outfall discharges into the river, where it leaves the immediate vicinity of the highway.

Pumping Station

The pumping station is a concrete and brick structure and contains two one-million-gallon pumping units and one two-million-gallon pumping unit of Worthington manufacture. There is nothing of special interest in connection with this pumping station except that the lift is accomplished inside the station, the discharge piping extending back into the suction well and rising vertically to a discharge chamber above. No check valves were installed on the discharge lines, the sewage flowing over baffles into the discharge channel. When a pumping unit is cut off the line by its float switch, it reverses in rotation and drains back into the suction well. The bar screens, 3 inches in the clear, protect the sewage pumps and disposal plant from large rags in the village sewage. However, the sewage from the Trudeau Sanitarium reaches the trunk sewer beyond the pumping station and is not screened.

Office Building

The floor of the office building was raised about 18 inches to avoid a boiling fine sand which yielded poor bearing values. This change required an alteration in the original drawings and also affected the inlet end of the settling tanks. The office building contains a water supply well and pump, together with a hydropneumatic tank, the source of water supply being ground water. There is also a sludge well and sludge pumping equipment for the fresh sludge from the blow-off manholes in the settling tanks and a dewatering well and dewatering pump for ground water and the settling tank themselves. The pumping equipment is located in the basement of the building, together with a small gas-fired hot water boiler for heating the building. The gas is piped to the heater from the sludge digestion tank cover. The main floor of the office building contains an office room, electric room and a tool room. The influent to the three settling tanks is conducted through a concrete conduit underneath the ground floor of the office building and the flow of the tank units is controlled by sluice gates operated from the tool room. This room also contains the control for the sludge conveyor. In the office there is installed a recording float gauge register which records the head over the over-flow weir as the sewage effluent leaves the settling tank.

Settling Tanks

The three settling tanks are of the shallow tank design with hoppers at the inlet end and plain floors and are equipped wth parallel sludge conveyors. The settling tanks were designed for a population of 15,000 people in 1930 and room has been allowed on each side of the existing battery of tanks to install two additional units which would increase its

capacity to serve a 25,000 population. For the present population of 11,000 people, the detention period is 2.94 hours and the average velocity is 0.85 inch per second. These settling tanks were installed partially in ground water. If they had been designed with a structural floor to support flotation, a great deal of expense would have been added to the construction costs. The flooring consists merely of a 6-in. slab of concrete with light reinforcement, but is supplied with scuppers, covered with bronze caps lightly caulked into place at the floor level. These scuppers drain into a series of underdrains under the tank floor and the underdrains extend to the dewatering well. If it is desired to dewater a tank, the dewatering pump is put into operation and the ground water surrounding the tank is removed through the underdrains. The tank itself can then be dewatered without upward hydrostatic pressure on the floor. However, should the operator forget to dewater the area around the tank before he started to dewater the tank itself, the scupper covers will blow out and the hydrostatic pressure would be relieved.

The parallel sludge collectors are of Jeffrey manufacture and return as skimmers along the water level of the tank. The influent channel is of concrete with multiple inlets to provide equal distribution of flow, and tests subsequently described will indicate that this objective was approximated. The sludge blow-off manholes are equipped with screens on the outlet side to protect the sludge pumps from large rags from the Sanitarium. The sludge pockets themselves are of a special design required primarily for structural reasons. When the floor level of the office building was raised to avoid unsatisfactory bearing values the bottom of the sludge hoppers also had to be raised and a special concrete construction substituted for that originally planned. To regain the hopper capacity which was thus lost, concrete boxes, 3 feet square and 3 feet deep, were sunk into the sand and the sludge blow-off piping extends within 6 inches of the bottom of these hopper extensions. In operation, these sludge hopper extensions have proved of advantage to concentrate fresh sludge.

Sludge Tanks

The sludge digestion tank was designed for 14,000 people, and assuming 25 cubic feet of sludge per thousand per day and a daily sludge contribution of 350 cubic feet, the digestion tank supplies 40 days' storage on the above basis and contains 14,000 cubic feet. The sludge tank is equipped with a Downes floating cover, with four fresh sludge inlets. The digestion tank is 30 feet in diameter by 20 feet in height with a four hopper bottom extending to an additional depth of 3.5 feet. It is equipped with two heating coils at mid-height of 2 in. tempered copper tubing with welded joints. The sludge storage tank was designed on the basis that if the

fresh sludge accumulated at the rate of 25 cubic feet per thousand per day, stored digested sludge would be reduced to a volume of about 12.5 cubic feet per thousand per day. This tank is 30 feet in diameter and 17 feet in height with one hopper 5 feet deep, and contains 13,000 cubic feet or 74 days' storage for a digested sludge with a moisture content of about 90 per cent. It will be noted that the operation of these tanks has not conformed with the original design and the storage tank has been used for various other purposes.

Between the two tanks a control house was installed which contains pipe and fittings, valving and accessories so that fresh sludge can be pumped to the digestion tank, to the storage tank or to the beds. This equipment also provides for the transfer of digested sludge to the storage tank, to the beds or to the sludge pump well. In a separate room of the control house draw-off piping is located at different elevations in the digestion tank wall and provision is made for withdrawal of sludge liquor, yellow sludge or black sludge. The control house also contains a heating boiler which is gas-fired from gas collected from the floating cover. The gas-fired boiler has four burners, is equipped with a circulating pump on the return line, water and gas meters, supply and return thermometers, condensate, flame and relief trap. The house also provides room for the storage of lime, and a liming tank, tools and accessories.

Sludge Beds

The sludge bed area was designed for 14,000 people at one square foot per capita. The total bed area is divided into four units by baffles 14 inches high. Each one of these sub-divisions is supplied with two industrial tracks, which carry a light truck for moving dried sludge from the beds and conveying it to a storage platform extending along the end of the beds. A depressed roadway serves the platform so that the stored sludge can be readily shoveled into a truck body. The sludge bed is equipped with underdrains, but due to the sandy soil no seepage has been intercepted by these drains.

Screenings

The screenings removed from the pump-house bar screens average about 1.6 cubic feet per day. The majority of the material caught on these screens consists of paper and gauzes, and large rags. As already stated, the sewage from the Trudeau Sanitarium enters the truck sewer from below the pumping station and some trouble was experienced with the sludge pumps at the sewage works, due to the lack of screening of this part of the sewage. The Sanitarium was cautioned about the matter and screens were installed in the sludge blow-off manholes to protect the sludge pumps. The screenings removed at this point average about 1.3 cubic feet per day.

Tests of Settling Tanks

Before the settling tanks were put into permanent operation, one unit of the tanks was used for experimental purposes and a series of tests was undertaken, which related to the operation of parallel sludge collectors, and the deposition of sludge. These tests were made for the Jeffrey Manufacturing Company, and through the courtesy of this company a brief summary of results are given here.

Tests of power consumption by the parallel sludge collectors were made in the month of January and it was found that when the motor and motor gear and jack shafts were run free without movement of the three conveyors, the power consumption was 0.644 kw. This power consumption resulted from static resistance, due to cold bearings and the operation of motor, gears, etc. When one of the conveyors was thrown into operation, the power consumption was not increased and after the bearings had warmed all three of the conveyors were put into operation and the initial power consumption was not increased. The first tank thrown into operation was cleared of sludge, the second tank contained a 12-hour deposit of sludge and the third tank, a 24-hour deposit of sludge. These varying conditions did not affect the power consumption. In the regular operation of the plant, the power consumption for the operation of the sludge conveyors at Saranac Lake is about one kw. hr. per day.

Tests were made to determine the best method of operating these sludge conveyors for Saranac Lake conditions. One tank was left without sludge removal for 48 hours. The sweeps were then operated for one-half revolution, the tank de-watered and the bottom examined. It was found that the bottom was as clean as if the sweeps were operated continuously. As a matter of daily practice, the sludge collectors are operated for about one-half revolution in the morning and one-half revolution in the afternoon. During the cold weather of January and February no trouble was experienced with freezing of the sewage surface and no interference occurred with the operation of the flights on their return as skimmers. The minimum temperature experienced was about 10 degrees below zero.

A large number of tests were made to illustrate the relative deposition of sludge in a full-sized settling tank under normal working conditions and with various velocities of flow. Metal containers and glass jars were set on the bottom of one unit at different locations in the length and cross-sections of this tank. The sludge collected by these containers and jars was measured by pouring the sludge into an Imhoff cone, allowing 15 minutes settlement in each case and converting milliliters of sludge into feet depth of deposition over the area of the aperture of the container. A complete analysis of sludge deposition would, of course, require a very complete set of tests extending over a long period of time. Variable action of sludge deposition on different days was apparent and in order to get

check tests on the different days of the week, it would be necessary to extend such tests over at least two months. It was apparent that sludge deposition varied with the daily character of the sewage and was affected within a certain range by the average velocities. The jars located on the same transverse section of the tank gave fairly uniform results, indicating that the distribution of flow through the tank was approximately uniform. It was found that when a container was raised two feet above the bottom of the tank, or even one foot above the bottom of the tank, it intercepted slightly more sludge than a similar container set on the floor of the tank at the same location. The diagrams resulting from these tests suggested a sludge stratification, *viz.*, what might be termed heavy sludge, medium sludge and light sludge. The heavy sludge, falling in the early percentage of the length of the tank was not noticeably affected by variations in velocity. The location of the peak deposition of the medium weight sludge was affected by tank velocities and as the velocity was increased this peak in the diagram was transferred toward the outlet end of the tank.

Table I gives a summary of the results obtained. It must, of course, be understood that this work related purely to percentages of the total sludge deposited in any given experiment and did not primarily relate to the variations in the total sludge intercepted in different experiments with various velocities. The work suggested the possibility that the inlet sludge pockets could be designed to receive a larger percentage of sludge by gravity without being handled by the conveyor and that the conveyors might be set forward in the tank by the use of two sludge pockets so that the conveyor would handle only medium weight and light sludge.

TABLE I

SLUDGE DEPOSITION TESTS

	Percentages of Total Sludge Deposition at Various Distances from Inlet at Various Percentages of Tank Length											
	7.5′ 10%	11.25′ 15%	15′ 20%	18.75′ 25%	22.5′ 30%	30′ 40%	37.5′ 50%	45′ 60%	52.5′ 70%	60′ 80%	67.5′ 90%	75′ 100%
Velocity—0.09″/sec.	51	57	61	65	70	77	83	88	91	95	97	100
Av. of velocities—0.09″ to 0.13″/sec.	38	45	52	60	68	79	84	90	93	96	98	100
Velocity — 0.376″/sec.	28	35	40	45	50	60	69	78	87	92	97	100
Av. of velocities—0.14″ to 0.376″/sec.	28	31	36	43	50	62	71	79	86	92	97	100

It is of interest to note that as an average of all tests and all velocities, 33 per cent of the total deposition took place in the first 7.5 feet (or 10 per cent) of the tank length; 70 per cent of the total sludge dropped within the first 30 feet (or 40 per cent) of the tank length; and 90 per cent

of the total dropped within the first 52.5 feet (or 70 per cent) of the tank length. These results were obtained by plotting the depths of deposition at the various locations and connecting these points with straight lines, and computing total and partial areas under this curve.

Operation of Settling Tanks

After the painted slopes of the sludge pockets had become well filmed with sewage grease and the Sanitarium had reduced the amount of large rags admitted to the sewers, fresh sludge has been blown off readily with little hoeing of pockets. The vertical section of the sludge pocket has helped to concentrate sludge around the riser and as this column drops it undermines the sludge on the slopes of the pockets. The sludge is blown with less than two turns on an 8-inch valve, and the pockets are gone over twice, both in the morning and afternoon. The Saranac Lake sludge sometimes tends to rise in mats, even without entrained gas, but quickly drops again when broken up with a rake. Very little skimming of the tanks has been required. The fresh sludge is particularly heavy in character and of a wood pulp consistency. The table indicates an average fresh sludge removal per day of 565 cubic feet or about .051 cubic feet per capita per day.

The tank effluent yields no readable settling solids in an Imhoff cone after two hours. It is soapy in appearance, but apparently free of settling solids. The diffusion at the outfall sewer, in normal flows of the river, nullifies any evidence of sewage within a flow distance of 20 feet away from the outlets.

Sludge Digestion

The sewage works were put in service on December 10, 1931. Due to a small leak in the digestion tank, the first fresh sludge was pumped to the storage tank. On December 21, 1931, this leak was repaired, fresh sludge was pumped to the digestion tank and that in the storage tank was transferred to the digestion tank.

On January 30, 1932, the sludge temperature was 48° F. and was raised to 52° on January 28 by a temporary coal heater which was replaced by a vertical type kerosene burner installed under the heating sections of the gas-fired boiler.

Daily reports were started on January 22, 1932, at which time the tank temperature was 52° F., pH was 6.6 and 10 bags of lime had been used. On February 1, tank temperatures were 64° at the top and middle, and 48° at the bottom; the pH 7.2, 7.2 and 6.8, respectively; 17 bags of lime had been used and about four million B. t. u. were applied daily to the digestion tank. Intermittent gas collection was started on February 10. This first gas production supplied buoyancy to the sludge rather

than agitation and a large volume of the sludge rose to the top of the tank. There was no heat conveyance through this heavy yellow floating sludge, it chilled, frosted and bound the cover. With the cover fixed, the dome seal blew on pumping sludge and no continuous record of gas could be obtained during February. Bottom tank temperatures lagged until the end of the month. On March 1, an inspection showed the cover fixed and attempts to cut out frosted sludge were unsuccessful. The dome cover was removed and frosted sludge was found around the intersection of dome and ceiling plates. The floating sludge was over 4 feet thick, dry, compact and cold. The sludge hose was disconnected from the sludge header and hot sludge liquor was pumped onto the roof of the cover and the frosted material quickly thawed out. Jetting through the dome, with hot sludge liquor, was started at once and later a permanent jetter was installed in the dome cover. This jetter consisted of a $1^1/_2$-in. brass pipe, extending through a stuffing box, installed in the center outlet of the dome cover, equipped with nozzle and hose connection. This riser can be raised and lowered and rotated. Proper pressures are not available as the hot sludge liquor has to be pumped by the sludge pumps, but the desired results have been obtained. The floating sludge was wet down, diluted, warmed, agitated and some of it settled. The floating sludge was, of course, inert in its chilled and dry condition and gas production lagged.

March 1 found outdoor temperatures still below freezing. The average B. t. u. input to the digestion tank was about four million. The pH started to fluctuate widely though 69 bags of lime had been used in February. The top sludge had a temperature of only 48°, while the liquor in the tank was at 78° to 82°. The pH suddenly corrected itself to 7.4 throughout the tank and gas production was 900 cubic feet on the 15th of March. The gas burners were started on March 27, with the use of the oil burner at night.

By April 1 the floating sludge had been raised in temperature to 66°, but later cooled off and did not reach average tank temperatures until May. Jetting was still employed, the gas supply was inadequate but the use of oil was stopped for economy. Gas production improved and reached 6500 cubic feet per day as a maximum with an average of 4800 cubic feet.

During May, gas production lagged for the first half of the month and tank temperatures receded. Sludge was drawn in May to the amount of 7700 cubic feet. This relieved tank congestion but reduced the seeding ratio. The temperatures and gas production were corrected toward the end of the month, the average gas being 4800 cubic feet per day. The pH was definitely established at about 7.4 with a total of 210 bags of lime and no lime has since been used. The temperature could have been

rectified with the oil burner but it was decided to await warm weather. The pH samples were filtered during May and trouble was experienced with commercial filter papers. Refined papers were substituted and eventually discarded in favor of dilution with distilled water.

With June outdoor temperatures of from 60° to 70°, necessary heat was available for the floating sludge and the tank at large and an explosive activity took place, due to delayed digestion and sludge foamed over the cover. The remote possibility of acid foaming was investigated but the pH was found to be 7.4. The gas meter proved too small and was replaced with a large meter. Maximum rates of gas collection exceeded 16,000 cubic feet per day.

The digestion tank was immediately starved of fresh sludge and the tank temperature dropped. Gas registration for this month was incomplete and the actual flow was much more than shown in the table, due to blowing of seals, bleeding at dome, etc. After the larger meter was installed gas registration increased to 13,000 cubic feet per day. Jetting settled much of the floating yellow sludge and toward the end of the month the tank quieted down. The sludge liquor during this period of violent action was turbid and the black sludge seriously thinned out. Only 2800 cubic feet of digested sludge were drawn during the month and proved to be dilute sludge.

The month of July was uneventful. The fresh sludge pumped temporarily to storage was gradually returned to the digestion tank without dropping the pH. Gas collection reached a maximum of 15,200 cubic feet and averaged 9150 cubic feet per day, and tank temperatures averaged 80 degrees. Gas production felt the delayed effect of starving during June.

In September a two-stage digestion was initiated by drawing off yellow floating sludge, black sludge and sludge liquor and filling the storage tank. The digestion tank has thus been well cleared of excessive floating sludge and is in good shape for the winter. Before winter sets in the slower digestion in the storage tank will have been completed and this tank can be drawn off onto the beds. This two-stage digestion will, of course, reduce the registered gas collection as the gas yield from the removed yellow sludge will be wasted in the ventilation of the storage tank.

Sludge Liquor

Sludge liquor or so-called supernatant liquor has been drawn from the digestion tank to the settling tanks every day, with the exception of those periods when no fresh sludge was pumped to the tank and when the floating cover is being raised preparatory to drawing digested or yellow sludge. This withdrawal of sludge liquor has approximated the volume of fresh sludge pumped to the digestion tank. The liquor is drawn from

the best outlet, by test, and in the morning before the tank has been disturbed.

Digested Sludge

The first withdrawal of black sludge was made in May after the tank had been in service for about four months. The original sewage for testing the tank was probably not displaced with fresh sludge until February 1, and proper temperatures were not attained until May. This withdrawal was premature, as far as securing a high-grade sludge is concerned, but the sludge was handled readily in spite of its thinness. The sludge of May was not of the best color and had a very slight odor. The withdrawals of May relieved tank congestion but reduced the seeding ratio.

Much better sludge was obtained in July and even better in October. Sludge will be withdrawn before winter sets in, but not in a quantity to reduce the seeding ratio unduly. The contents of the storage tank will be withdrawn to the beds and marginal capacities will thus be availabe for a severe winter if it occurs.

TABLE II

OPERATING DATA, SARANAC LAKE, N. Y., SEWAGE WORKS

Month	Kw. Hr. Pumping	Kw. Hr. Plant	Average Mill.* Gals. Sewage	Daily Cu. Ft. Wet Sludge	pH	Sludge Temp.	Mill. B.t.u.	Cu. Ft. Gas	Bags Lime	Total Cu. Ft. Sludge Drawn
Jan.					6.6				17‡	
Feb.	187	8.6		630	7.2	77	4.0	700**	69	
Mar.	180	15.4		542	7.1	80	4.13	1,480	96	
Apr.	252	19.3		480	7.4	80	2.55	4,350	27	
May	209	11.0	1.92	545	7.4	78	2.26	4,800	1	7700
June	170	10.0	1.78	555	7.4	82	1.41	6,427†	..	2800
July	167	13.2	1.73	573	7.4	80	1.35	9,150	..	8400
Aug.	165	9.7	1.34	610	7.4	80	1.54	11,380	..	
Sept.	138	9.0	1.13	580	7.4	83	1.70	10,000	..	2800
Av.	184	12.0	1.58*	565	7.3	80	2.37	6,798	210	21,700

* Approximate only.

** Last few days of month.

† Not complete. ‡ Total for month.

General Plant Operation

Table II gives the principal data relating to the plant operation. No laboratory work is done, but pH and temperature determinations, putrescibility tests, measurement of fresh sludge and sewage flow are maintained. For the first six months the plant was under the general supervision of this office, which designed and supervised the construction of the plant.

The Saranac Lake plant is under the supervision of the City Manager and is operated by one man, who performs all work, including removal of sludge from beds. The superintendent is only occasionally assisted by a crew from the water and sewer department for special work.

Explosion and Health Hazards in Sewage Works Operation*

Presented at the Fifth Annual Meeting of the New York State Sewage Works Association, New York City, January 17, 1933

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It is common knowledge that combustible gases such as manufactured gas used in our homes may, under certain conditions, produce explosions, also that combustible liquids such as gasoline may cause explosions. However, these facts cause us little worry. Our experiences have shown us that the use of gas in our homes is attended with little danger. Likewise gasoline is handled and dispensed to the public on almost every corner. This combustible liquid is poured from pumps to our automobiles, often without special care, and yet explosions are seldom caused in the handling of these combustible liquids. These every-day experiences with combustibles have a tendency to create an attitude of carelessness and disregard of the precautions to be taken in the handling and treatment of combustibles.

Gases are produced in sewage sludge-digestion tanks that are combustible and, due to the high methane content, resemble natural gas used in many of our cities. Most every one familiar with sewage gases is aware that these gases under certain conditions are toxic, and when mixed with air in the right proportion may cause explosions. Several bad accidents resulting from the explosion of gases from sewage sludge-digestion tanks, and death to employees caused by the toxic effect of these gases, have forcibly brought to the attention of municipal engineers and the public the necessity of greater precautions in the handling, disposal and utilization of these gases.

Hazards Involved.—There are two definite hazards involved in the handling, disposal and utilization of sewage gas: first, the explosion hazard, and second, the health hazard due to the presence of toxic constituents and the low oxygen content of the gas.

Explosion Hazards.—Briefly reviewing the fundamentals of explosions, we find that four factors are essential for the production of an explosion, as follows:

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Editor's Note.—This paper is a slightly condensed draft of a similar paper presented June 23, 1932, by the author before the Pennsylvania Sewage Works Association. The New York paper contains additional practical information for the sewage works operator.

- (*a*) Combustible material
  - Gases
  - Liquids
  - Vapors
    - Vapor pressure
    - Flash point
  - Mists
  - Solids
- (*b*) Oxygen supply
  - Normal air
  - High oxygen content
  - Deficient in oxygen
- (*c*) Ignition sources
  - Flames
    - Open lights
    - Matches
    - Cigar lighters
    - Fires
  - Sparks
    - Sparks from tools
    - Lightning
    - Electric shorts
  - Heated materials
    - Heated metals
    - Hot cinders
    - Glowing tobacco
    - Lighted cigarettes
- (*d*) Distribution of oxygen with respect to the combustible.

All ordinary combustibles which are capable of producing explosions when mixed with the proper proportions of oxygen and ignited, contain one or more of the following elements: Hydrogen, carbon, sulphur. These three elements plus oxygen and nitrogen comprise most of the elements in which the investigator of explosions is interested.

Under combustibles there are three classes of materials, namely, gases, liquids and solids.

Under gases we have a great variety of substances: the element hydrogen, combinations of hydrogen and sulphur (for example, hydrogen sulphide), carbon and hydrogen compounds which comprise the paraffin hydrocarbon series, methane, ethane, propane and butane found in natural gas, and methane, ethane, carbon monoxide, ethylene and propylene in manufactured gas.

A review of the analyses of gases from sludge digestion tanks, as reported in the literature, shows that the mixture is complex, and to consist of carbon dioxide, hydrogen, methane, nitrogen and at times small amounts of hydrogen sulphide and oxygen. A tabulation of results of analyses of typical sewage gases is given in Table I. This tabulation shows that the carbon dioxide content may vary from about 3.0 to 30.0 per cent, the oxygen from 0.0 to 1.2 per cent, the hydrogen sulphide from 0.0 to 0.1, the hydrogen from 0.0 to 8.2, the methane from 63.0 to 84.2 per cent.

It is seen that the combustibles which contribute to the explosive hazards are methane and hydrogen. Hydrogen sulphide forms an explosive mixture when mixed with the proper proportions of air, but the amounts present are so small that hydrogen sulphide may be disregarded with respect to explosion hazards.

From the standpoint of health the toxic gas, hydrogen sulphide, is of first

TABLE I

COMPOSITION AND INFLAMMABLE LIMITS OF GASES FROM SEWAGE SLUDGE DIGESTION TANKS

Sample Number	*a*	*b*	*c*		*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	
Source	Imhoff Tank		Septic Tank		Imhoff Tanks				Imhoff Tanks				
Remarks					Foaming		Non-foaming		Lower Compartment		Upper Compartment		
Reference	1	1	2	2	2	2	2	2	3	3	3	3	Range
Carbon Dioxide	4.4	5.2	13.6	17.0	19.8	29.4	3.3	28.5	11.8	9.6	20.0	23.4	3.3 to 29.4
Oxygen	0.6	0.5	0.0	0.0	0.3	0.0	0.0	0.0	1.2	1.0	...	...	0.0 to 1.2
Hydrogen Sulphide	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	...	...	0.0 to 0.1
Hydrogen	7.9	8.2	3.5	0.0	0.0	0.0	0.0	0.0	4.6	0.0	1.8	1.7	0.0 to 8.2
Methane	84.2	82.8	72.5	78.0	68.7	66.6	78.2	63.0	70.2	66.1	70.0	67.5	63.0 to 84.2
Nitrogen	2.9	3.3	10.4	5.0	11.2	3.9	18.5	8.5	12.2	23.3	8.2	7.4	2.9 to 23.3
Inflammable Limit, Lower	5.30	5.30	6.55	6.70	7.40	7.80	6.40	8.30	6.55	7.80	7.55	7.80	5.30 to 8.30
Inflammable Limit, Upper	16.00	16.10	17.90	16.65	18.25	18.35	16.85	19.15	18.45	19.25	18.45	18.50	16.00 to 19.25

References: 1. C. C. Hommon, "Gas from Imhoff Tank," *Eng. News*, **71**, 760 (1914).
2. A. M. Buswell and S. I. Strickhouser, "Some Observations on Sewage Tank Gases," *Ind. Eng. Chem.*, **18**, 407 (1926).
3. H. E. Babbitt and H. E. Schlenz, "Results of Sewage Treatment," Univ. Illinois, *Bull.*, No. **198**, 88 and 92 (1929).

importance. Because of the absence of oxygen, one would become quickly suffocated in this gas. The toxic effects will be discussed a little later.

Under liquids there are (disregarding high explosives) two classes of substances which may produce explosive mixtures: first, vapors, and second, mists. The important factor which determines whether combustible liquids may liberate a sufficient amount of vapor to produce explosions is the vapor pressure.

Some combustible liquids at room temperatures do not have a sufficiently high vapor pressure to produce explosive mixtures when mixed with air, others may produce explosive mixtures, while others may give mixtures above the upper explosive limit.

The second important factor which determines whether combustible liquids may produce explosive mixtures is the flash-point. The flash-point is usually stated as that temperature to which a combustible liquid must be heated to produce a flash when a small flame is passed across the surface of the liquid. The higher the flash-point, the more safely can such combustible liquids be handled. Cleaners' naphthas having a flash-point of about 100° F. are relatively safe from explosive hazards when used and handled at ordinary room temperatures, others having a lower flash-point (60° to 80° F.) are very dangerous.

Next under combustible liquids to be considered are mists. Liquids having low vapor pressures and therefore high flash-points, as just stated, cannot normally produce explosive mixtures at ordinary temperatures. However, if such combustible liquids are violently agitated so that very small droplets, or mists, are produced, such mixtures with air are explosive. Such mixtures may be produced by passing compressed air through a liquid whereby the liquid is atomized in a manner similar to that accomplished by devices used on oil burners. If agitation ceases the mists in the air soon settle out and dangers from explosion are removed.

Next to be discussed is the explosibility of combustible solids. Under solids there are almost unlimited combustible materials which, when finely ground and suspended in the air, will explode with great violence when ignited. Of chief importance in the mining industry is finely pulverized coal dust. Outside the mining industry there are many dusts that may form explosive mixtures. Sugar and starch dust have caused some very disastrous explosions and even soap dust may form an explosive mixture. The dust which accumulates in vehicular tunnels, consisting of abrasions from automobile tires, brakes, etc., has been found to produce explosions when mixed with the proper proportions of air and ignited.

Oxygen Supply

Under oxygen supply three conditions may be present. First, and in most cases, the oxygen supply is that present in normal air. Normal air

contains 20.93 per cent oxygen, 0.03 per cent carbon dioxide, and the remainder nitrogen and inert gases. It is remarkable that the percentage of oxygen in normal air is practically constant throughout the world, provided it is not contaminated by industrial gases, gases from volcanoes, and so forth.

Most combustible gases, when mixed with air in explosive proportions and ignited, develop rather high pressures and may at times develop flame speeds varying from a few feet up to, say, 1000 feet a second; these same combustibles if mixed with atmospheres containing oxygen in proper proportions may detonate when ignited. Then, instead of developing flame speeds up to 1000 feet a second as with normal air, these combustible mixtures may develop speeds of 10,000 feet a second and do tremendous damage.

If the oxygen concentration of our atmosphere greatly exceeded the normal value of 20.93 per cent, combustion processes once started would be very difficult, if not impossible, to control.

On the other hand, should the oxygen content fall much below 20.93 per cent our habits and mode of living would be greatly altered. Natural gas cannot be made to burn when the oxygen content is below 12.0 per cent; neither will gasoline burn or explode when mixed with an atmosphere containing less than 12.0 per cent oxygen. Ethylene flames are extinguished when the oxygen content falls below 10.0 per cent, and carbon monoxide and hydrogen flames fail to propagate when the oxygen content is reduced below about 5.5 per cent.

One can tolerate atmospheres containing 12.0 per cent oxygen; however, one becomes easily tired and his efficiency is greatly reduced. Workmen would require frequent rest periods. The partial pressure of oxygen at the top of Pikes Peak, Colorado, is equivalent to about 13.5 per cent at sea level.

An oxygen content of 20.93 per cent as found in our normal atmosphere seems to be the ideal concentration for our well-being. Most combustibles burn well in this mixture and combustible processes can be controlled. Ammonia gas is the only combustible that could be used with greater efficiency if the oxygen content of our atmosphere were more than 20.9 per cent. Ammonia when mixed with air in the proper proportions will propagate flame upward and horizontally, but not downward. With higher concentration of oxygen than that found in normal air, it will propagate flame in all directions and might under these conditions be useful in combustion processes.

The fact that all combustible gases, vapors and solids will not burn or explode when the oxygen content is reduced below certain definite values, varying with the materials under consideration, gives the safety engineer a means of definitely controlling and eliminating explosions. This method

is being extensively used at the present time for preventing explosions in industrial equipment, in fighting mine fires, and could be applied to gases from sewage sludge-digestion tanks. Flue gas or automobile exhaust gas has a low oxygen content and is ideally suited for reducing the oxygen content of explosive mixtures. Carbon dioxide and carbon tetrachloride and the new gas, dichloro-difluoro-methane, have also been used or suggested.

Ignition Sources.—Before an explosive mixture can be made to explode a portion of the mixture must be heated to its ignition temperature. The ignition temperature may be defined as that temperature at which rapid combustion becomes independent of external supplies of heat.

The investigation of ignition temperatures is complicated and the results obtained are affected by a number of variables, the most important of which are the percentages of combustible in the mixture, the oxygen concentration, the "lag," or time required at a given temperature to cause ignition, the size, composition and kind of apparatus used, the pressure on the mixture when ignition occurs, and the presence of small amounts of catalysts or of impurities in the mixtures.

In spite of the widely varying results that are reported for the ignition temperatures, the data are useful for rating the relative tendency of different materials to become ignited. For example, phosphine will ignite at ordinary temperatures. When this gas is generated under water, the bubbles on reaching the surface and on coming in contact with air will ignite and burn. Some phosphine gas may be generated in sewage tanks and as a result may be the source of ignition of explosive mixtures of sewage gases and air.

Other series of compounds have ignition temperatures varying from 120° to 300° C. In this class comes carbon disulphide which has an ignition temperature of 120° C. This temperature is only slightly in excess of the temperature of steam pipes. Other substances coming in this class include most of the ethers and a few hydrocarbons found in gasoline. All of these compounds can be ignited by heating a glass rod to temperatures well below a visible red heat when viewed in the dark.

From 300° to 500° C. come motor fuels, alcohols, kerosene, naphthas, acetylene and hydrogen sulphide. Hydrogen sulphide, which is sometimes found in sewage gases, has an ignition temperature varying from 346° to 379° C.[1]

From 500° to 700° C. are included most of the permanent gases such as methane (645° C.),[2] ethane, propane, butane, hydrogen (502° C.),[3] carbon monoxide, ethylene, benzene, toluene and xylene.

[1] Dixon and Coward, *Jour. Chem. Soc.*, **95**, 514 (1909).

[2] Jones and Seaman, unpublished results.

[3] Dixon, Higgins and Harwood, *Trans. Faraday Soc.*, **22**, 267 (1926).

Above 700° there is ammonia, which has an ignition temperature of 780° C.[4]

Since the combustibles in sewage gas comprise methane, hydrogen and hydrogen sulphide, it seems probable that the ignition temperature of sewage gas will be somewhat below 645° C., the ignition temperature of methane, and above 346° C., the ignition temperature of hydrogen sulphide. The ignition temperature of mixtures of combustibles cannot be determined by calculation from a knowledge of the ignition temperatures of the individual constituents. Traces of some substances as, for example, nitrogen peroxide greatly reduce the ignition temperature of methane-air mixtures, while, on the other hand, minute additions of iodine and some chloro-hydrocarbons raise the ignition temperatures.

The safety engineer is largely interested in the sources of ignition which may cause mixtures of sewage gas and air to explode. These may be divided into (1) flames, (2) sparks and (3) heated materials. From the standpoint of the ignition of sewage gases, under flames there might be mentioned open lights, burning matches, cigar lighters and fires; under sparks might be given sparks from tools, lightning and electric short circuits, and under heated materials might be mentioned glowing metals, hot cinders, glowing tobacco in pipes and lighted cigarettes.

Distribution of Oxygen with Respect to the Combustible

The distribution of the oxygen with respect to the combustible is very important. Gasoline when properly vaporized and mixed with the proper portions of air forms highly explosive mixtures as for example gasoline-air mixtures in internal combustion engines. However, if I place a pan of gasoline on this table surrounded with air and ignite it, the gasoline merely burns with a smoky flame because the combustible and the oxygen supply are not intimately mixed.

Combustible gases and vapors are not dangerous from the explosion standpoint so long as the oxygen supply is not intimately associated with the combustibles. The combustibles (if not contaminated with air) will merely burn the same as an ordinary flame. There are no special dangers from explosions so long as we keep the combustibles on one side of the fence and the oxygen supply on the other. The dangers arise when the two become intimately mixed together in the right proportions and become ignited. These right proportions come under the heading of explosive limits.

Limits of Inflammability

An inflammable mixture such as methane in air may be diluted with air, or methane added until the mixture will not propagate flame when

[4] Holm, *Zeit. für agewandte chem.*, **26**, 273 (1913).

ignited. These limiting or borderline mixtures which will just propagate flame are designated limits of inflammability. There are, therefore, two limits of inflammability, an upper and lower for each combustible. The lower corresponds to the minimum amount of combustible, the upper, the maximum amount of combustible capable of conferring propagation of flame in the mixture when ignited. For example, for methane-air mixtures these limits under normal conditions are approximately 5.0 and 15.0 per cent, respectively. Mixtures within these limits liberate enough energy on combustion of any one layer to ignite the neighboring layer of unburned gas and therefore capable of self-propagation of flame; others are not.

Factors Affecting Limits of Inflammability

Source of Ignition.—When a source of heat of sufficient size and intensity as introduced into a weak mixture, that is, one just below the lower limit, some combustion occurs. This is usually visible as a "cap" of flame. As the lower limit is approached this flame "cap" enlarges, for example, in a miner's safety lamp the cap may entirely fill the interior portions of the lamp within the gauze. Such flames are not self-propagating because they are extinguished when the influence of the source of ignition is removed. The source of ignition does not affect the limits of inflammability provided the ignition source is of sufficient intensity to initiate the propagation of flame.

Direction of Flame Propagation.—When a source of ignition, such as an electric spark or a flame, is introduced into an inflammable mixture, flame tends to travel away from the source in all directions. In a very large volume of mixture the form of the zone of combustion would be a spherical shell of increasing radius, were it not that the hot gases of combustion tend to rise and hence introduce convection currents.

Flame cannot travel downward when the upward movement of the gases, due to convection, is faster than the speed of flame in a still mixture, as happens in weak mixtures near the limits of inflammability. Hence near each limit there is a range of mixtures which will propagate flame upward but not downward, and therefore the limits are wider when flames are propagated in an upward direction than for horizontal or downward propagation of flame. For safety in industrial operations values for upward propagation of flame should be taken.

Diameter of Explosion Apparatus.—Observations should be made in apparatus wide enough that the cooling effect of the walls is negligible. The observed limits of inflammability are always widened as the diameter of the apparatus is increased, rapidly at first and more slowly as the diameter approaches two inches. For diameter greater than two inches there is very little difference in the limits.

Length of Test.—The apparatus should be of sufficient length to make certain that flame continues to propagate after the heat imparted to the mixture by the source of ignition has been dissipated. An apparatus three or more feet in length is sufficient to determine whether flame continues to propagate.

Ignition from a Closed End and Turbulence.—In some cases it has been found that ignition from a closed end and gentle turbulence reduces slightly the lower limit.

Effect of Temperature.—Ordinary variations of laboratory temperature have no appreciable effect on the limits of inflammability. Elevated temperatures do have an effect on the inflammable limits, because to propagate flame, the layer of unburned gas next to the burning layer must be brought to such a temperature that it will burst into flame. If the unburned gas is already at a temperature above that of the laboratory, less heat has to be supplied from the burning layer, therefore the lower limit is decreased by increase of initial temperatures and the upper limit is raised.

Effect of Pressure.—The normal variations of atmospheric pressure have no appreciable influence on the inflammability. The effect of large pressure increases on the limits of inflammability is becoming of great importance due to the extensive employment of high pressure reactions at the present time. The effect of high pressures on the limits of inflammability is neither simple nor uniform but specific for each inflammable mixture.

Effect of Humidity.—Humidity or water vapor content of most combustible gas mixtures changes the lower limit of inflammability only to a slight extent at laboratory temperatures.

Carbon monoxide is an exception to the rule; the lower inflammable limit is raised with reduced water vapor content, and, in fact, if dried over phosphorus pentoxide the mixture is exceedingly difficult to ignite.

An increase in the water-vapor content in a combustible gas mixture reduced the upper limit somewhat due to the fact that the water vapor replaces part of the oxygen present, thereby reducing the amount of combustible which can be burned and the limit is lowered.

Calculation of Limits of Inflammability

We are now able to calculate quite closely the limits of inflammability of not only complex gases containing only hydrocarbons, but also mixtures containing large amounts of inert gases. The limits of inflammability of natural, manufactured, producer, blast furnace, automobile, and sewage gases may now be quite accurately calculated from a knowledge of the composition of the gas in question and the limits of inflammability of the constituents. The actual procedure of calculating the limits of inflam-

mability of complex gases is rather long and complicated. For those who are interested in the subject reference should be made to the original reports.[5] This method of calculating the inflammable limits of complex gases has been of great value to safety engineers and should be of special value in determining the explosive hazards of gas from sludge-digestion tanks. In Table I, showing the composition of sewage gases, the limits of inflammability have been calculated. The results show that the lower inflammable limit may vary from 5.30 to 8.30 per cent by volume, while the upper limit may vary from 16.00 to 19.25 per cent.

Physiological Effects of Sewage Gas

Inspection of the composition of the sewage gases given in Table I shows that from the standpoint of health there are three hazards involved; first, the presence of hydrogen sulphide in some of the sewage gases; second, high concentrations of carbon dioxide in most of the samples, and third, a deficiency of oxygen in all of the samples.

Hydrogen Sulphide.—Hydrogen sulphide is an exceedingly toxic gas. Its presence in very low concentrations can usually be detected by its characteristic odor, which resembles that of decayed eggs. However, in high concentrations the gas paralyzes the olfactory nerves and no odor may be detected even when hydrogen sulphide is present in fatal concentrations. Sayers[6] and others have shown that subacute poisoning may be produced by long exposures to concentrations as low as 0.005 per cent. Exposure to these low concentrations causes irritation of the respiratory tract and depression of the central nervous system. Acute poisoning is produced when the concentration varies from 0.06 to 0.08 per cent, causing action on the nerves, which results in paralysis of the respiratory system, heart failure and death on continued exposure.

The results given in Table I show that 0.1 per cent of hydrogen sulphide was present in one of the samples. Continued exposure to this concentration would be fatal to any one entering a sewage tank without proper protection.

High Concentrations of Carbon Dioxide.—Carbon dioxide is a colorless and odorless gas about one and one-half times as heavy as air. It is produced in practically all combustion processes. The expired air from one's breath contains from 4.0 to 5.0 per cent carbon dioxide. A person at rest can breath 2 per cent carbon dioxide in otherwise pure air for a period of several hours without ill effects. Three or 4 per cent causes an oppressive feeling, producing shortness of breath or panting, especially if one is work-

[5] Coward and Jones, U. S. Bureau of Mines, *Bulletin* **279** (1931). Jones, U. S. Bureau of Mines, *Technical Paper*, No. **450** (1929). Jones and Kennedy, U. S. Bureau of Mines, *Report of Investigations*, No. **3172**.

[6] U. S. Bureau of Mines, *Bulletin* **231** (1925).

ing. Five to 6 per cent produces stronger panting, headache, flushing of face, and it is possible to do very little work at these concentrations. Seven to 10 per cent may be fatal, depending on the length of exposure and whether the subject is active or at rest. The sensations of a subject in high concentrations of carbon dioxide have been described as follows: There is a sensation of great weight on the head, of pressure in the temples, of ringing in the ears, a pungent sensation in the nose, of giddiness and loss of muscular power and a strong desire to sleep.

Oxygen Deficiency.—Oxygen deficiency appears to be the chief cause of the fatalities to persons entering sewage tanks. The best report on the effect of atmospheres deficient in oxygen is that given by Haldane,[7] the eminent English physiologist. He states that if the oxygen content is reduced to 12 per cent respiration becomes just perceptibly deeper. At 10 per cent the respirations are distinctly deeper and more frequent, and the lips become slightly bluish. At 8 per cent the face begins to assume a leaden color, though the distress is still not great. With 5 or 6 per cent there is marked panting, and this is accompanied by clouding of the senses and loss of power over the limbs, which would end sooner or later in death.

Experiments made by Burrell[8] in which he breathed an atmosphere containing 7 per cent of oxygen produced unconsciousness after continued breathing of this atmosphere. In recent tests, made by the author, of a manhole atmosphere in which two men were overcome but later recovered, the oxygen content of the atmosphere varied from 6.7 to 8.4 per cent by volume. It is impossible to set a definite value for the minimum oxygen concentration which human beings may breathe without danger. The value necessarily depends upon the general health of each individual, his stamina, and the amount of work he is doing. It is probably safe to state that men should not work in atmospheres containing less than 12 per cent of oxygen and it is decidedly dangerous if the oxygen content is below 10 per cent.

The analyses of sewage gases given in Table I show the oxygen content to be less than 2.0 per cent. Such atmospheres would cause the collapse and death of any one breathing the atmospheres in less than a minute.

The review just given shows that gas from sewage disposal plants is exceedingly toxic because of the hydrogen sulphide which may be present, the high percentages of carbon dioxide, and the low percentages of oxygen. No one should be allowed to enter such atmosphere without being protected by an approved hose mask or a self-contained oxygen breathing apparatus.

[7] J. S. Haldane, Report to Secretary of State for the Home Department, p. 15 (1896).

[8] George A. Burrell and G. G. Oberfell, U. S. Bureau of Mines, *Tech. Paper*, 122 (1915).

As has been mentioned, sewage gases may become highly explosive and are very toxic, and it is recommended that sewage tanks be well ventilated before workmen are allowed to enter them for inspection or making repairs. The problem is similar to that encountered in mines. Combustible and toxic gases are liberated in many mines and the solution has been the adequate ventilation of all mine workings to keep the concentrations of the gases well below the lower inflammable and toxic limits.

Since, as previously stated, the lower inflammable limit may be reached when the concentration of sewage gas equals about 5.00 per cent, it is evident that a tank must be thoroughly ventilated, if explosions are to be prevented. There are satisfactory types of portable blowers now on the market for ventilating manholes. Any of these might be satisfactorily used for ventilating sewage tanks when inspection or repairs are to be made. These blowers should be provided with flame-proof motors. It should be strongly emphasized that ventilation should be continued during the time workmen are in the tanks, because the sludge in the tanks will continue to give off gas and may easily equal the lower inflammable limit unless this gas is continuously swept out with air as fast as generated.

There are several gas detectors now on the market that may be used for determining when the atmosphere in the tank is safe to enter. However, some of these detectors are not flame-proof and only those that have been approved for use in mines should be taken in the tanks. If illumination is required in the tanks only approved flashlights should be used.

Flame Traps.—At many sewage treatment plants the gases are collected and used for heating purposes. The utilization of these gases is attended with some hazards. Very little trouble should be experienced when the plant is in continuous operation, because the gas as produced contains very little oxygen and should be as safe to use as ordinary manufactured gas. However, if the plant is shut down or gas generation stopped, air may leak into the distribution system and thus produce explosive mixtures.

Of chief importance to prevent the infiltration of air is to keep the entire system under a few inches of water pressure above atmospheric so that leakage will be from the system rather than into it. If air can be kept out of the system, then explosions will not be possible.

Even under the best operating conditions there may be times when the system will contain some air, especially when first put into operation. Precautions must then be taken to prevent flames from traveling through the distribution mains and causing bad explosions. Sir Humphrey Davy over a hundred years ago discovered that fine-meshed screens placed around the flame of a miner's lamp would prevent the flame inside of the lamp from igniting explosive mixtures of methane in air on the outside. Since that time many uses have been made of this discovery, more espe-

cially the arresting of flames in pipe lines. I think the safety features claimed for screens in systems containing large volumes of gas have been overrated. They are excellent protection for "stationary" flames as found in a safety lamp or even for flames moving at a slow speed, but for flames which in pipes of sufficient size and length may travel 1000 feet a second and develop high pressures, several screens in tandem will be required and even then if the flame has been arrested the high pressure is still present and must be eliminated if damage is to be prevented. Our experience gained last year on another problem, whereby means of preventing damage to industrial equipment from explosive mixtures were investigated, led to the conclusion that release diaphragms are the most satisfactory method of protecting systems containing explosive mixtures. Release diaphragms properly placed and of the right size, augmented by water seals and screens, should give satisfactory protection to sludge gas systems. On account of a lack of information on the flame speeds and pressures developed when explosive mixtures of sewage gases are ignited in pipes or other chambers it is not possible to state definitely how and where the diaphragms should be placed. Information on other explosive mixtures in general permits us to reason by analogy what might be adequate for sewage gases. I might say, as a mere speculation, that if release diaphragm openings are installed on the flame trap of a sewage pipe system in the proportions of 3.5 square feet of release opening per 100 cubic feet of gas, the release opening be 6 inches or larger in diameter, aluminum, lead or tin foil be used for diaphragm material, and not over 0.002 inch in thickness, then the pressure in the flame trap caused by the explosion of any sewage gas-air mixture should not exceed 12 pounds per square inch above atmospheric pressure. The installation of two flame traps close together and at the delivery end of the sewage gases, so assembled that the traps may be connected in series or parallel, and each equipped with the proper diaphragm releases, water seals and screens, should safely prevent flames from traveling through the piping systems to the sludge-digestion tanks. The traps should be equipped with suitable gauges to give the pressure of the gas in the traps and the height of the water above the water seals.

Two flame traps are recommended because in case of trouble in either, the gas may be passed through one while the other is being repaired. During normal operation both may be used as an added protection.

It is very important that the water in the seals should be kept at the proper height at all times, the screens kept clean, the flame traps placed in a heated and well-ventilated part of the building and protected by an enclosure so the diaphragms may not be damaged, and that employees may not be burned by flames issuing through the diaphragm openings, should an explosion occur.

Fact and Fancy in Sewerage Financing*

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A taxpayer has been facetiously described in recent years as a man who wants public water supply, sewerage facilities, paved streets, street lighting, police protection, fire protection, health department supervision and no taxes. In this aphorism lies perhaps the explanation for much of the discussion which has arisen in the last four or five years regarding the financing of every form of public utility. The financing of public sewerage systems is only one sub-division of the general problem, age old in character.

So much has been written about the financing of sewerage systems in the last five years, particularly with reference to sewer rentals, that it is unnecessary to repeat some of the outstanding facts which have been presented in detail elsewhere. This is particularly true in the light of the very excellent review of the sewer rental program recently prepared by Childs and Schroepfer.[1]

In view of the abundant literature on this topic, therefore, the writer will restrict himself to a description of the philosophy of financing sewerage systems, with particular reference to the psychology of the taxpayer.

TABLE I

CHRONOLOGICAL PROGRESS OF PAPERS ON SEWER RENTALS

Year	Number of Papers	Remarks
1894	1	
..		
..		
1921	1	
1922	0	
1923	0	
1924	1	
1925	0	"The Golden Age"
1926	2	
1927	3	
1928	3	
1929	8	
1930	8	"The Depression"
1931	4	
1932	10	The Reconstruction Finance Corporation Act

* *Presented before the Fifth Annual Meeting of the New York State Sewage Works Association, New York City, January 17, 1933.*

In doing so the author will present his own views briefly as to some of the current difficulties in municipal finance. A brief review of the chronological order of appearance of published documents on sewerage service charges or rentals sheds considerable light on the origin of much of the practice in municipal finance. In Table I a list is presented of the number of articles dealing with the financing of sewerage systems which have appeared each year since 1894 to date. The list has been compiled from the very complete bibliography presented in the paper[1] by Childs and Schroepfer, supplemented by a few papers not included by those authors. The year 1894 was chosen as a base because it was in that year that the City of Brockton instituted the use of the sewer rental plan for meeting part of the costs of a sewerage system. Reference to Table I discloses a number of interesting facts, the importance of which will appear later. In the interval from 1894 to 1923, virtually no literature appeared in the field on the important problem of sewerage financing. One of the few exceptions was a paper in 1921 in which the present writer was joint author. The absence of discussion on this matter was not due to the absence of the necessity of formulating a sane program of finance for sewerage, as sewerage construction from 1894 to 1923, a period of thirty years, was at no low figure. Some other explanation for the deficiency in public writing and discussion must be found.

During the 1923 to 1928 period, now popularly known as "the golden age," additional papers appear, but still comparatively few in number and largely restricted to one or two authors. The real epidemic nature of the production of papers on sewer rentals began at the end of 1928 and had not yet reached its peak at the end of 1932. The epidemic is synchronized almost completely with the collapse of the economic system at the end of 1928 and so far has shown two peaks of epidemicity. One of these peaks occurred in the period 1929 to 1930, almost simultaneously with the universal attack on the high cost of municipal service and on excessive tax rates. A second and higher peak of epidemicity occurs in 1932, concurrently with the passage of the Reconstruction Finance Corporation Act and its now famous "self-liquidation" clause.

These characteristics of the epidemic curve of literary production on sewer rentals appear to me to have a peculiar significance in relation to the problem of financing sewerage systems. Emphasis on this device of meeting either the fixed or operating charges or both received its first impetus in the universal popular revolt against the inflexibility and the amount of the general real estate or property tax. It received a second boost when the Reconstruction Finance Corporation, by virtue of the restriction in the Congressional Act, suddenly discovered that the only way in which a sewerage system could be considered as "self-liquidating" would be through the payment of the fixed and operating charges on the system

by means of sewer rentals. The points which the writer would like to stress in this connection are that

(1) The sewer rental as a method for paying for certain portions of sewerage service is at least a half century old, and

(2) The present emphasis on its use as a universal panacea for many municipal financing difficulties is the result of an artificial set of circumstances. The writer hastens to add, however, that these conclusions have nothing whatever to do with the validity of the application of the sewer rental plan to situations where it is both logical and equitable.

One of our recent well informed writers on taxation, Herbert D. Simpson, in speaking of the incidence of real estate taxes, states, "A representative of one of the largest development companies in Chicago, in 1928, stated that 'we don't figure on taxes at all' and that was the truth throughout most of this period. Speculative profits, actual and anticipated, were so liberal that taxes seldom entered into the decision when or where to build or whether to build or not."[2] Cycles of preference for methods of paying for public service of one kind or another are not rare in the history of this or any other country. Illustrations of such cycles within comparatively recent years in this country are given at somewhat greater length below. It is my intention to make clear, however, in all that follows, that underlying any plan for financing, there is the psychology of the public to be considered. At the moment, the public is universally attacking that one obvious fortress of cost, the general tax on property. That source of income, for the United States at large, accounts for virtually 65 per cent of all the revenue for local government.[3] As far as the home owner is concerned, it is a painfully direct tax. It cannot easily be shifted. It is a lump sum payment with delinquent and penalty dates. It is as inevitable as death and its recurrence as regular as life. The facts throughout this country will support the further statement that the present difficulty with municipal taxation is not its amount or its injustice, with relation to the service rendered, but its inevitability and the impossibility of shifting it.

When confronted with these resultants of an economic collapse, every student of municipal enterprise in this country has sought new forms of revenue to pay for old forms of activity. In so doing, there has been a grand rush to the rental form of activity, not only because it may be equitable, but because it is different from the property tax, frequent in the billing to the consumer and more closely linked with the service applied.

Dykstra[4] has recently pointed out in a very careful document on "The Real Cost of Municipal Retrenchment," that one of the most objectionable features of the general property tax is that it appears only once a year. It lacks the psychological advantage that every public utility service bill carries with it, namely, monthly or quarterly billing and specifying of the particular service for which the bill is rendered.

The psychological and fiscal disadvantages of attempting to construct and operate sewerage systems by property taxation alone are more pressing now then ever. Some brief comment is desirable, therefore, upon the alternatives available. These alternatives to general taxation should be considered primarily from the standpoint of logic and equity, rather than from that of temporary expediency and popular hysteria, even when such hysteria is reinforced by ill-advised legislative fiat.

Basic Principles of Financing Sewerage Systems

The theoretically ideal program for meeting the cost of public sewerage systems has been carefully set forth by Morse and Wolman[5] in 1921. The writer does not feel that he has much additional to contribute to what was there stated. The test of time has shown the validity of the philosophy there outlined, and a brief summary of that philosophy is here restated.

The plan was based upon the fundamental principles that public and private benefits should be separately considered and that there should be a differentiation between fixed and operating charges. The plan embodied the payment for sewerage systems by a combination of property tax, annual front foot assessment, house connection cash payment and sewerage service charge.

"Manifestly any plan of meeting the costs of construction, maintenance and operation of water supply and sewerage works should be founded upon the principle that the expense entailed upon any individual, public or private, should be proportionate to the benefits which he derives. A thoroughly equitable financial plan for constructing and operating water and sewerage systems must involve a combination of all the three methods indicated above. The mere presence of water works or sewerage in any town is of value to all of the taxable property, remote though it may sometimes appear.

"The only portion of the cost of water and sewerage service that should be allocated to the tax rate is the measure of value that such service represents to all the taxable property, unless a graded plan of taxation on the basis of geographical location is used.

"That part of the cost of service which represents a special value to all properties, vacant and improved alike, along water and sewer lines may be reasonably met by special assessment. The amount of this special assessment should be as closely as possible proportionate to the expense that the mere presence of the property entails upon the system. This expense is determinable by the length that the property binds upon the public way in which the pipe line is placed. In the case of a system properly designed this assessment should be independent of the size of the pipe in the street.

"The third class of benefit, and the greatest, is enjoyed by the developed

properties along the pipe lines, and it is the connection of such properties with the system and their use thereof which give rise to the major part of the costs of maintaining and operating the system.

"An exact analysis of the benefits received by the various classes of property above discussed is difficult of accomplishment. The problem may be solved, however, with a degree of approximation which will give a reasonably fair division of costs. The solution necessarily will be governed somewhat by local prejudices, and policy frequently dictates that such prejudices should determine the absolute amounts of the several classes of charges. Local feeling, however, should not be allowed to destroy the fundamental philosophy of the plan. There should be firm adherence to the principle that capital cost be met by the tax rate and by front-foot assessment, and that expense of maintenance and operation be covered mainly, if not wholly, by charges for service rendered."

The system with some modifications, depending upon local situations, has been applied in Maryland to the financing of the water supply and sewerage facilities for some 175,000 people. In its application a number of interesting situations have arisen, which illustrate the desirability not only of formulating an equitable program for financing, but more important of the necessity of adjusting that program to the time, the place and the people involved.

Deviations from Basic Principles

Sectional Prejudices.—Although a theoretically ideal plan for financing sewerage systems may find its way into the literature, it is only rarely that it will be adopted without modification by the area upon which it is to be superimposed. Even before the 1929 collapse, surprising differences of reaction of the people in various parts of this country appeared to various methods of financing undertakings. The present revolt against the installation of public works, for example, is not only a revolt against the principle of general taxation, but fundamentally against the expenditure of any further funds for public works. The writer believes that this is one basic reason why municipal work is not likely to proceed with any rapidity regardless of how many state-wide sewer rental laws are passed in the next two or three years.

In 1928, the writer was very much surprised at the quite benign acceptance of the front foot assessment plan for meeting some of the costs of sewers in Maryland and the very severe reaction against the front foot benefit program in that same year in Southern California. In the latter case, this method of financing apparently had been much overdone and bond issues based on the benefit plan of payment were being turned down.

In one part of Maryland the public objects strenuously to using any general taxes for the payment for part of the sewerage system, whereas in

another, not over forty miles away, a general tax as part payment is accepted without any contest. There appears to be little or no relation between the reaction of the taxpayer and the method of financing, excepting in so far as the time, the people and the place are taken into consideration.

Accounting Expense.—One of the difficulties in the way of the universal adoption of the sewer rental plan, in communities of less than 10,000, even if it were theoretically desirable, is in the costs of measuring and billing for this service. In the City of Salisbury, Maryland, for example, notices of front foot assessments for water supply and sewerage systems were all prepared at the completion of the system and were mailed during August, 1926. At a time set for the hearing, hundreds of property owners appeared protesting on this method of paying for the sewerage system. In addition to the assessment plan, service charges were to be included for the maintenance and operating costs. The front foot assessment method of financing met the general disapproval of the taxpayers, while the general tax to meet the entire cost of the system, raised no objection. Owing to the popular pressure, the method of financing the new system was immediately changed and a total of 34 cents per 100 dollars was added to the general tax. It should be remembered that this revolt *in favor of* a property tax occurred in 1926. What would happen in 1933, if the question were again raised, the writer would not venture to predict.

This general property tax is collected with the other city taxes by the city treasurer without additional cost, thereby affecting an annual saving of approximately $3000 in office expense. The plan adopted is not equitable, but the taxpayers thought so. The present method of paying for such service by general taxation appears to cut certain costs, but it does interfere seriously with the general validity of the financing plan. The maintenance and operation charges are largely met by service charges.

Control by Local Interested Groups.—Many examples have occurred in the writer's experiences where major adjustments in the financial program have been made to satisfy interested local groups, whether these are large property owners, farmers or tax-exempt property owners, is immaterial. Whether we like it or not they do account for many deviations from the theoretically desirable principles.

Conclusions

It may be safely stated from what has already been presented, both in this paper and in the literature at large, that no perfect syllogism for public works financing is at hand. Not even a theoretically perfect mathematical rule may be set up. Fundamentally, however, the guiding rule for the payment for a sewerage system should be that the base of payment be as close as practicable to the base of benefit. If this principle is rigidly followed, there is no escape from the use of the combination of the general

property tax, the front foot assessment and the service charge. The balancing of each of these three in the final formula is a matter of calculation and too frequently of adjustment to local prejudice.

That the latter frequently controls is attested by the fact that, of the total population of 29 million in the cities of 250,000 and over in this country, approximately 25 million pay for maintenance and operation of sewerage systems out of the general tax levy. Here again, the principle is not correct, but it is doubtful whether the wisdom of the specialist and the wish of the people will coincide more completely as time goes on, particularly when, as in recent months, the wisdom of the specialist is influenced a little too much by the expediency of the moment.

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Required Capacity of Separate Digestion Tanks for an Activated Sludge Plant*

BY W. S. STANLEY

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In calculating capacities of digestion tanks three factors should be taken into consideration:

First: Solids content of sludge or sludges to be digested.

Second: Digestion time needed to obtain sludge which will lend itself to further disposal with a minimum of cost and nuisance.

Third: Per cent reduction in volatile solids obtained through digestion.

This paper is the result of two years of operating experience and as such makes use of data obtained from actual practice at the San Antonio sewage plant. The facts and figures gathered during that period were assembled and analyzed. They all point to an important characteristic peculiar to the extreme south, namely, the low solid content of various sludges as obtained under local climatic conditions. The primary sludge averaged 4.5 per cent solids, the excess activated 0.8 per cent and the digested sludge 3.7 per cent.

Repeated attempts to thicken the sludges were followed by disastrous results. In the case of primary sludge the outcome was foul primary tanks with formation of heavy scum of septic material floating upon the surface and throughout the tanks. This septic matter entered the aeration tanks and upset the equilibrium of the activated sludge. With the activated sludge it was found that the thickening required an increased air supply which under existing economic conditions proved prohibitive.

The consistency of digested sludge cannot be controlled at San Antonio. It largely depends upon the age of the sludge, temperature in the tank as well as the frequency of removal. At no time during the plant operation was it found possible to obtain a digested sludge free from objectionable features in less than 60 days. This period must therefore be considered a minimum time for proper digestion.

In calculating the per cent reduction in volatile matter due to digestion, sludge introduced into digesters was compared with digested sludge drawn at the end of the digestion period. This was done in the following manner: Mixed sludge entering digestion tanks:

Fixed solids, 26 per cent; volatile solids, 74 per cent; hence each pound of fixed solids represents: $26:1::74:X$; $X = 2.84$ pounds of volatile solids.

Digested sludge, drawn from digestion tanks:

* *Presented before the Fifteenth Annual Texas Water Works Short School, Temple, Texas, January 16, 1933.*

Fixed solids, 37 per cent; volatile solids, 63 per cent; hence each pound of fixed solids represents: $37:1::63:X$; $X = 1.70$ pounds of volatile solids.

This means that for every 2.84 pounds of volatile solids introduced at the beginning of digestion we have 1.70 pounds of volatile solids left, or a reduction in volatile solids of:

$$\frac{(2.84 - 1.70) \times 100}{2.84} = 40 \text{ per cent}$$

Another important figure derived from actual operating experience and based upon data obtained from sampling at five different levels is that of the average solid content of a well balanced digestion tank while in service. This figure includes the bottom layer of properly digested sludge, the intermediate layers of partially digested sludge and the top portion of the tank consisting of comparatively clear supernatant with a small amount of scum. The average solid content of such a tank was found to be 2.75 per cent.

In San Antonio the daily amounts and composition of sludges to be digested are as follows:

	% Solids	% Volatile	Gals. per Day	Pounds per Day Total	Pounds per Day Vol.
Primary Sludge	4.5	75	45,000	16,900	12,700
Activated Sludge	0.8	73	300,000	20,000	14,600

This means that for every 45,000 gallons of primary sludge we have 300,000 gallons of activated sludge, or a relation of one part primary sludge to 6.66 parts of activated sludge. Thus the characteristics of the daily mixtures of the two sludges will be:

	% Solids	% Volatile	Gal. per Day	Pounds per Day Total	Pounds per Day Vol.
Mixed Sludges	1.3	74	345,000	36,900	27,300

Accepting the above figures as a basis for calculation, the problem is to arrive at a digestion tank volume, sufficient to retain all the solids introduced daily for a period of 60 days, allowing for daily shrinkage due to reduction through the digestion process. It is assumed that at the end of 60 days the first drawing of digested sludge will be made.

What actually transpires inside of a digestion tank during the process of decomposition is not definitely known. Of one thing we can be certain, namely, that the process viewed from a span of 60 days is fairly uniform. This is proved by the fact that the regular charging of a well balanced digestion tank with raw sludge and a regular removal of corresponding amount of digested sludge permits the digestion process to continue for an indefinite period without interruptions. Starting with an empty digester and adding equal amounts of sludge every day, at the

end of 60 days the digestion tank would hold sludge at 60 stages of decomposition: the sludge introduced on the first day would be digested 40 per cent and ready to be drawn, while the sludge introduced on the last day would be in its original undigested state. The intermediate stages would lie in between the two extremes. Thus for all practical purposes it is quite safe to assume that the digestion is proceeding according to arithmetical progression.

Using the formula $S = \frac{N}{2}(a + l)$; where $N = 60$; $a = 27{,}300$; $l = 27{,}300 \times .60 = 16{,}400$ we get at the end of 60 days: $S = \frac{60}{2}(27{,}300 + 400)$ = 1,311,000 pounds volatile solids, accumulated in the digestion tank.

The fixed solids, being undecomposable, or nearly so, would represent: $9600 \times 60 = 576{,}000$ pounds.

The total solids at the end of that period would amount to: 1,311,000 lbs. + 576,000 lbs. = 1,887,000 pounds.

Since the average solid content of digestion tank at that time is 2.75 per cent, the volume needed would be as follows:

$$V = \frac{1{,}887{,}000 \times 100}{2.75 \times 8.33} = 8{,}225{,}000 \text{ gallons or } 1{,}100{,}000 \text{ cubic feet.}$$

The present connected population of San Antonio is 180,000, to which must be added the night soil and packing-house equivalent of 20,000, bringing the total load to 200,000 population. Consequently the digestion capacity needed is 5.5 cubic feet per capita, or 40 cubic feet per pound of volatile matter added per day.

Functions of the Sewage Treatment Laboratory*

BY MICHAEL J. BLEW

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The laboratory control of sewage treatment processes varies from absolutely none in most cases to complete control in a relatively few instances. Failure on the part of the engineering profession in the beginning to recognize sewage treatment as a chemical engineering problem has been largely responsible for the slow development of this treatment. The greatest strides have been made in the past in those places where the laboratory has been used the most, and it is to be regretted that there were not more laboratory-trained engineers engaged in this work in the early stages of development. Even today, most schools of engineering pay too much attention to design and too little to the study of the fundamental scientific principles involved in the treatment of sewage.

Most of the antipathy exhibited by industrial engineers toward all stream pollution endeavors is the result of their misconception of the problem and utter lack of understanding.

All treatment plants, however small, should be provided with a laboratory where, at least, a few simple tests can be made. If the community is too small to provide a full time chemist, arrangements should be made for one on a part time basis to check the operation of the plant. In all cases, care should be exercised to see that the tests are conducted by a trained and honest worker; otherwise his work is useless.

In many cases an intelligent operator can be trained to carry on the simpler tests, such as free chlorine, relative stability, pH and settling solids. He must be an honest workman and his results must be checked and tabulated by some one with more training and experience. These tests constitute about the minimum amount of work that should be required of any plant.

There have been instances where the construction and equipping of a laboratory apparently have been done only to serve as a sort of alibi to higher authority and with no intention of controlling the process or of contributing to our knowledge of sewage treatment. There are other cases where the laboratory has been used to beguile a public disturbed over some local sanitary disturbance. In other cases, the chemist has been politically appointed and has been neither qualified nor interested in his work.

Samples are often taken improperly by dishonest or poorly trained samplers. Some of the common mistakes are to skip samples because of stormy weather; to fill the sample bottle at once instead of making com-

* *Presented before the Sixth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 23, 1932.*

posites over a period of time; to sample from improper places to save walking; to allow the samples to stand open either to evaporate in the sun or to collect dust from the air; to add additional disinfectant to a supposedly sterilized effluent to insure the sterility of the sample; to collect a greater sample from a peak flow than from the less concentrated night flows to indicate a greater removal than actually occurred; to decant the liquid from a sample before analyzing. These errors are based on actual cases of improper sampling. Time and money spent for chemicals used on such samples are completely wasted, and the results lead only to false impressions and confusion. In the first place, analytical data are worth no more than the honesty and integrity of the sample taker warrants.

After the sample has been carefully collected, transported and stored, it must be honestly analyzed. Careless, slipshod and unchecked work in the laboratory only leads to confusion and does more damage than good.

After the sample has been analyzed and a report rendered, the data must be tabulated as received and without change. The changing of data in tabulations to provide nice uniform decimal columns should never be tolerated. These apparent discrepancies almost always even themselves out and almost invariably a reason can be found for their existence. If they are out of line, an immediate search should be made to find the cause. That is really what constitutes plant control, and these evils just mentioned constitute the *abuse* of the laboratory.

The need for honor and integrity in the smallest things connected with the laboratory cannot be overstressed. It must be remembered that "Truth needs no defense, she only needs an honest investigator," and it is the function of the laboratory to discover the true conditions and to report them as found. What later becomes of the information is largely a question of policy.

The principal function of the laboratory is the routine examinations required to control properly the operation of the plant. The kind of tests and the amount of work done necessarily vary with the type of process carried on at the plant.

Sedimentation tanks, either mechanically cleaned or of the Imhoff type, can be tested for detention time and cross currents by any one of a number of simple chemical methods. Weirs can be calibrated and adjusted to provide an equal flow to each of a number of tanks. The percentage of removal can be determined and the resulting volume of sludge calculated.

The progress of digestion can be observed in digestion processes, and any disturbance overcome. The degree of digestion can be determined by the pH and ash content of the sludge. Foaming digestion tanks can be controlled by watching the pH of the supernatant sludge liquor. When lime is used as a conditioning agent, the pH is the quickest and most reliable indicator of the progress of treatment. Determination of ash in

sludge, together with the color, odor and general physical appearance, is the best criterion of when to draw sludge from the tanks.

In the operation of sprinkling filters, contact beds or sand filters, a record of suspended solids and B. O. D. best demonstrates the degree of treatment. In checking activated-sludge processes, the settling rate of the sludge should be made a routine procedure.

When the final effluent is chlorinated, the determinations of total bacteria, *B. coli* and free chlorine indicate the efficiency of the process. These same determinations indicate the bacteriological load on water purification processes when the effluent enters a stream used for drinking purposes.

Performance tests covering a period of from 12 to 24 hours, or longer, are splendid indicators of the true operating conditions at the plant. Such tests are laborious and require considerable work but they are well worth the effort required for they show the conditions as they are at any time during a long period of time. They should cover each sampling point for each hour during the day and night. Such tests are best conducted during periods of dry weather flow to reduce the effect of dilution from storm water and infiltration.

Sampling points should be carefully selected and used without change, if possible, to insure a sequence in data from year to year without error. It is a good plan to number the sampling points. All samples should be marked to correspond with the sampling points. Samples should be taken under the supervision of the analyst. Composites may be collected in many different ways, but the principal thing to remember is that the sampling method must be consistent.

Because of the influence of trade effluents on sewage treatment, the laboratory should be prepared to carry on investigations concerning these wastes. These studies follow well defined lines. First, to eliminate all waste materials causing excessive sludge or deposits in sewers and tanks or obstruction of pumps and other mechanical equipment. Second, to prevent the entry into the system of materials deleterious to the operation of biological processes. Third, to remove wastes damaging to the sewerage structures, such as acids, alkalies, oils and greases and chemicals. Fourth, to remove wastes having a high biochemical oxygen demand which would overload the treatment plant. Such wastes are generally organic and contain much animal and vegetable matter in solution and finely divided. The last consideration, but not the least in importance, is to prevent the loss of life or danger to health of workmen through the escape into the sewerage system of dangerous fumes and chemicals, gasoline or other explosives, live steam or hot water, suffocating compounds and dangerous bacteria, such as anthrax or tuberculosis. Effluents containing pathogenic bacteria should invariably be chlorinated or otherwise completely disinfected.

The sewage laboratory should also maintain a close check on all bodies of water subjected to contamination in the community. However large or small the stream may be into which the effluent passes, the stream should be examined above and below the outlet at frequent intervals to detect any changes occurring for better or for worse. The dissolved oxygen test is an excellent indication of the condition of surface waters, but should be augmented by carbon dioxide and bacterial determinations.

Every operator and every chemist should be encouraged to do such experimental work as his time will permit. Almost every plant offers some features that are worthy of being checked and reported upon. The stimulation afforded any one by simple investigation and the re-discovery of old facts gives the operator a wonderful sense of satisfaction. Only by such endeavors can new facts be uncovered.

Such men as are equipped by training and have the proper laboratory equipment should be encouraged to conduct experimental work along lines that are not strictly connected with the operation of the plant. Satisfactory methods for the treatment of most trade effluents are not at hand and all of them are worthy of serious consideration. All routine tests should be done according to standard methods of the American Public Health Association, but there is plenty of room for the checking of old methods and the development of new ones. Studies are in order linking the science of sewage treatment to public health and also to questions of water supply.

Most plants are constructed with the intention of their extension at a future date. The laboratory can be of tremendous use in supplying information for the extension when the time comes. Data concerning the volume of sewage treated, rates of flow, rates of treatment, doses of chemicals, strength of sewage, sludge produced per capita and per million gallons, and the biological load on oxidizing processes, can be tabulated for later use. Such information is invaluable and often very hard to procure.

In some localities, sewage treatment is looked upon as some sort of nefarious enterprise. Sound information and skilful propaganda can come from the laboratory to help sweeten the public mind.

In many instances, well kept laboratory records have helped to save a community from damage suits. Well kept records look good in court and go a long way in the defense of an otherwise defenseless plant.

When two communities live on the same stream there is always a potential danger of the one above being sued for damages by the one below. Very often neighbors take offense at the presence of a treatment plant and seek to use it as the means of picking up some extra cash. Discharged employees sometimes talk long and loudly about things their imagination conjures up within themselves. In all these cases, well kept laboratory records are the solution to the problem.

There are always many special studies to be made which are often done under laboratory jurisdiction. Infiltration, flooding, nuisances, leaks, odors, corrosion, gas in sewers, clogged sewers, etc., are all, at times, investigated under laboratory supervision.

Many unnecessary records are kept and essential ones neglected. Records to be kept must not be so voluminous that the task becomes too irksome or else it will not be done at all. The data can be listed under Chemical, Bacteriological, Physical and Operating heads.

Chemical data consist of the daily, weekly or annual chemical determinations necessary to obtain representative averages of plant results. In analyzing sewage many determinations are necessary to obtain a good average. The more determinations the more valuable the average becomes. Many different determinations are made on sewage and they vary from place to place. The most important ones are the suspended solids bio-chemical oxygen demand, oxygen consumed, dissolved oxygen, hydrogen-ion concentration, grease and oil, total solids, ash and volatile matter, free chlorine and possibly one or two special ones. Many people tabulate free ammonia, total nitrogen, nitrites and nitrates. As a rule these are not so satisfactory for plant control as the B. O. D., and generally speaking this determination, plus pH and suspended solids, will suffice for the control of any kind of plant.

The bacteriological data consist generally of total bacteria and *B. coli*. In checking up a digestion process it is often well to count the number of red or acid-producing bacteria as well as the *B. coli*.

Physical data consist of the temperatures of air and sewage, wind velocity and direction, rainfall, per cent of sunshine and such information as would shed light on the happenings in and about the plant. Many of these data can be used in making an interpretation of the chemical and bacteriological findings, especially when apparent discrepancies occur.

Operating data are essential to the compilation of accurate cost information. The number of hours the plant was in operation (daily, weekly and monthly); number of hours for each unit; the power consumption; gas consumption when sludge tanks are heated or screenings are incinerated; the weight of chemicals used daily and per million gallons; the cubic feet of sludge, screenings and grit produced per day and per million gallons of sewage; the disposition of screenings, sludge and grit; and the general manipulation of the plant—all should be recorded. In addition, stream flow data should be kept when possible.

The method of tabulation of data varies with individuals, but whatever system is used it should be consistent from year to year. Daily records can be taken and averaged by the week or by the month. Monthly and annual averages are valuable. The monthly average indicates the seasonal changes taking place, whereas the annual average indicates gross changes

taking place in the influent or in the plant operation over a long period of time.

The percentage efficiency of the plant or of parts of the plant are valuable indications of the operation, and are easily indicated by the percentage removal.

After the data are prepared they can be presented in several ways. The most affective manner is by the use of tables and graphs. Tables of monthly and annual averages are good and should be prepared and preserved, but a simple graph indicates more at a glance than a whole book full of figures.

The laboratory can conduct many little special tests that prove useful and interesting, such as the testing of paint on and around sewerage structures, concrete preservatives, metals and metal coatings, and chemicals and equipment used in the plant. Bleaching powder, alum and lime should be analyzed by the alert chemist.

The training of sample collectors and technicians and in some cases the training of the operators as well, properly comes under the head of the laboratory. If the operation of the plant is to be conducted as a chemical engineering undertaking, all three of these divisions very properly belong under the jurisdiction of the laboratory or in close liaison with it.

In most plants the chemist is looked upon as the first-aid man and the laboratory as the haven of refuge for all the aches and pains about the place. Every cut and bruise about a sewage treatment plant is potentially serious and may possibly lead to serious infection. Dried sludge and stale sewage, especially, seem to contain many fungi and mold spores and are potentially breeders of skin irritations. Where sludge or screenings are burned there is danger of burns and where gas is collected there is danger of explosion and asphyxiation. The laboratory should be prepared, and the chemist should be expected to furnish first aid in all such cases until the patient is taken to a hospital or until a physician arrives.

Most plants have an abundance of flies and mosquitoes. A certain amount of preventive work should be done, guided by the chemist. When screenings are buried, there will always be plenty of rats in the dump. Mild deratization measures can be conducted without great cost.

Following is a recommended list of determinations on different effluents.

(1) Primary Sedimentation: B. O. D., suspended Solids. Settling Solids in Imhoff cone, Ether Soluble Matter in influent and effluent.

(2) Sprinkling Filters, Contact Beds and Sand Filtration: B. O. D., Suspended Solids or Relative Stability when the laboratory is small.

(3) Activated Sludge: B. O. D., Suspended Solids, Total Bacteria and *B. coli*.

(4) Sludge, fresh, digested or activated: Ash, Volatile Matter, Grease and Oil, pH.

(5) Chlorination: Free Chlorine, Total Bacteria and *B. coli*.

(6) Chemical Precipitation: Suspended Solids, Settling Solids, B. O. D., Alkalinity, Total Bacteria, Chemicals Used.

(7) Trade Wastes Suspended Solids, Total Solids, Ash and Volatile Matter, Ether Soluble, Oxygen Consumed, Bacteria, *B. coli*, Alkalinity and possibly special tests for specific wastes.

(8) River Surveys: Dissolved Oxygen, B. O. D. (when badly polluted), Bacteria. *B. coli*, Snails, Crustacea, Plankton, etc.

This concludes a fairly inclusive list of the possibilities of a sewage plant laboratory. It is not supposed that each and every laboratory fulfills all of these missions. There are many duplications, and the duties never are quite the same in different plants. A laboratory should be planned for every plant, equipped as well as possible, and then used to the fullest extent of all its possibilities.

Discussion

MR. F. W. JONES, Cleveland: I think there is just one thing that engineers forget in regard to laboratories—how to get them. There should be some provision made looking toward some laboratory control, even in small plants. For that reason it is well to include in the original plans and contract both laboratory and equipment and also small tools and equipment which are essential to a plant. It is surprising to see how much apparatus you can buy for $150, and that for any plant is a very small item. If you are going to have a laboratory at all it should be properly equipped. It is surprising also how the most humble operator can be instructed. We showed one operator how to make tests for *B. coli* and I am sure that if I practiced for 100 years I could not have obtained the dexterity that man has. The manner of sampling is quite important. Many times we get into the habit of using the laboratory test as a mere form and we feel that we have to go through with it in some form. We just go through the motions without thought. That applies particularly to suspended solids. If a man does that and in the course of three months the Imhoff tanks are filled up with solids, and he does not stop to think there is something wrong—well, he ought to lose his job.

Industrial Wastes and Stream Pollution

Studies of the Effect of a Small Impounding Reservoir on Stream Purification*

By G. M. Ridenour

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Introduction

A search of the literature will show that some extensive investigations have been made on the biological self-purification of large sewage-polluted streams through atmospheric reaeration, photosynthetic re-oxygenation, and decomposition of objectionable organic material by aquatic plant and animal life. Numerous calculations have been presented showing the rapidity of recovery of sewage polluted streams. However, very little detailed information has been published on the effect of natural storage reservoirs wherein these same physical and biochemical factors apply in aiding the recovery of similarily polluted streams.

This paper is prepared to show the results and interpretation of data gathered during the past year on a comparatively small stream receiving a heavy pollutional load of domestic sewage and upon which a small impounding reservoir is located. The study is of interest in showing the effect of this reservoir in promoting the recovery of the stream.

The conditions under which these studies were carried on are briefly summarized as follows: The proportion of sewage flow to stream flow was large, consequently the pollutional load was comparatively great. The impounding dam is sufficiently near the sewage outfall that practically no self-purification occurs between the point of pollution and the reservoir. Unrestricted vegetative conditions existed in the reservoir. No additional pollutional matter entered the reservoir other than the pollution mentioned.

Since these studies were conducted during both summer and winter the data collected will serve to show a comparison between these two seasons of (1) the effect of the impounding reservoir on the reduction of biochemical oxygen demand, (2) reduction of organisms of the colon group, (3) reaeration effects due to the dam overfall, (4) dissolved oxygen depletion in the reservoir and (5) the coefficients of deoxygenation and re-aeration through the pond.

* *Journal Series Paper of the N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

The months of June, July and August have been taken to represent the summer months and December, January and February the winter months.

General Description

This investigation was conducted in connection with studies on the

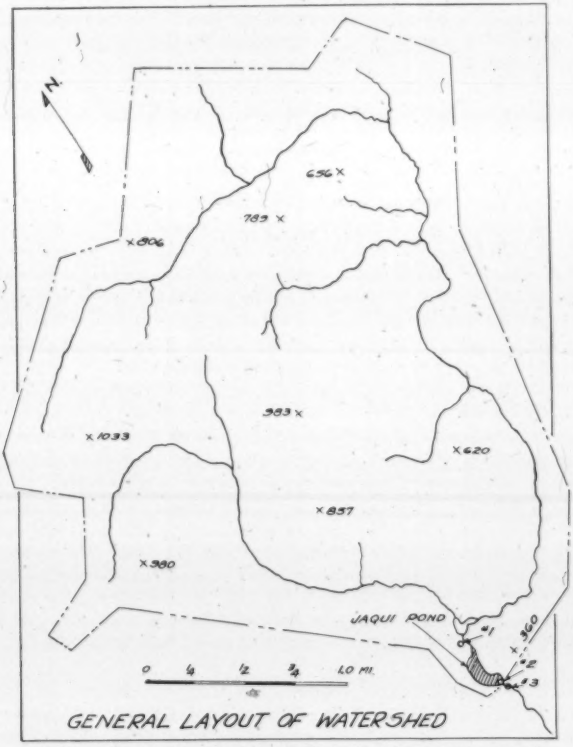

FIG. 1.—General Characteristics of Watershed Area and Layout of Pond.

sewage treatment plant at Greystone Park State Hospital, one of the New Jersey state institutions located at Morris Plains, N. J.

A plan of the general layout and watershed area, is shown in plan in Figure 1.

The watershed area above the sewage outfall from the institution is virtually unpolluted by any domestic or industrial wastes discharging directly into the streams.

The sewage from the institution enters the stream about 500 feet above the head waters of the reservoir.

Sampling point No. 1 was located approximately 200 feet below the sewer outfall, No. 2 in the reservoir just above the dam and No. 3 in the stream about 100 feet below the dam.

Description of the Reservoir

The impounding reservoir has an average width of approximately 300 feet and a length approximating 750 feet. The depth of the reservoir at

FIG. 2.—Photograph of Pond.

the toe of the dam is 15 feet. The surface area exposed is 225,000 square feet. The total estimated capacity is 2,000,000 cubic feet or 15,000,000 gallons. On the basis of the average summer period, sampling day flows, this capacity provided a theoretical detention period of 2.8 days. The minimum theoretical detention period during this summer period was 0.9 of a day and the maximum 4.9 days. On the same basis the average detention during the winter season was 3.0 days with a minimum of 1.5 days and a maximum of 3.8 days. Figure 2 shows a photograph of the reservoir.

Natural vegetative and animal growths prevail in the reservoir comparable to all uninfluenced growths found in streams or bodies of water receiving moderate amounts of freshly introduced organic matter. During the summer season algae are quite abundant. The most noticeable growth

during the past two seasons appeared in the form of *Lemna* which for a short interval covered approximately 50 per cent of the entire surface area of the lake.

The drop from the crest of the dam to the stream bed below the dam is approximately 16 feet. Within this drop the overfalling water is well aerated by the projecting, irregular, down-stream face of the structure.

Figure 3 shows the character of the overfall and down-stream face of the dam.

Source and Character of Pollution

The only source of pollution, other than a negligible amount of unsewered runoff, comes from the Greystone Park Insane Hospital.

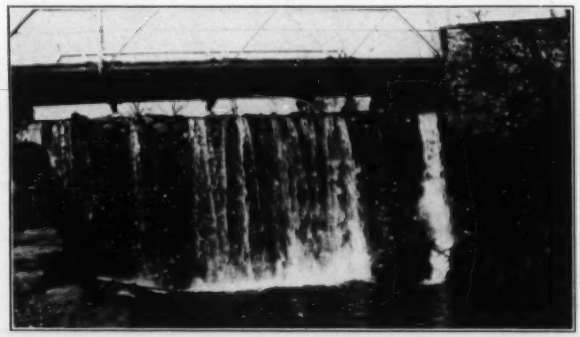

FIG. 3.—Overfall from Dam.

The sewage before being discharged into the stream is treated by preliminary settling, separate sludge digestion, trickling filters and chlorination. The pollutional load on the stream as a result of the plant effluent and B. O. D. in the stream above the outfall amounts to an average of 1860 population equivalent. This has been calculated on the basis of 0.2 pound of oxygen per capita per day.

The average, maximum and minimum B. O. D. (5 days) for the two seasons in the stream at the station above the reservoir was:

	Average	Maximum	Minimum
Summer	13.7	24.0	5.4
Winter	15.3	27.0	8.1

Stream Flow Data

The stream flow entering the reservoir is formed by a drainage area of 6.4 square miles. This area is of a hilly character with comparatively

quick runoff factors. Consequently the stream above the dam is of a flashy nature, subject to rapid increases in flow.

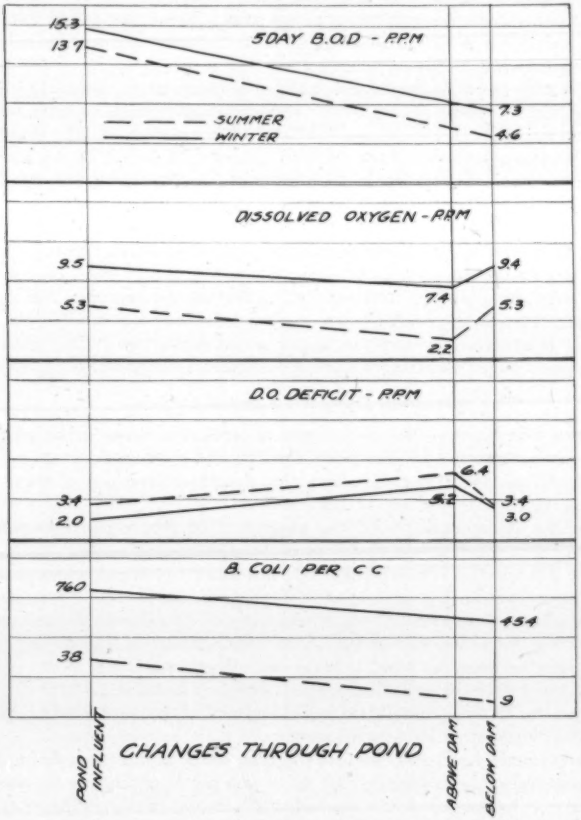

FIG. 4.—General Overall Purification Characteristics of Pond.

The average stream discharge for the summer sampling period under study was 8.3 cu. ft. per sec. with a minimum of 4.7 c. f. s. and a maximum of 27.0 c. f. s. During the winter period the average was 7.7 c. f. s. with a

minimum of 6.1 c. f. s. and a maximum of 15.5 c. f. s. These discharges have been calculated by pro-rating the measured discharge of the Whippany River at Morristown in proportion to watershed areas. The area of the total watershed contributing to the stream flow at the gauging station at Morristown is 29 square miles which includes the 6.4 square miles of watershed above the Jaqui pond.

The general purification characteristics of the pond are shown in Figure 4 for both the summer and winter periods. This figure shows the actual reduction in B. O. D., *B. coli* (24-hour presumptive test) and dissolved oxygen through the pond for the two seasons. The effect of the overfall from the dam in increasing the D. O. saturation is also shown.

B. O. D. Reduction

With respect to removal of putrescible organic material, Figure 4 shows that during the summer season the average reduction in B. O. D. through the pond amounted to 66.5 per cent. During the summer period the temperatures in the pond averaged 21° C. In comparison with this, the B. O. D. reduction during the winter period amounted to 52.5 per cent with an average pond temperature of 6.2 degrees centigrade.

Dissolved Oxygen Furnished by Pond

Some calculations show an interesting similarity between the amount of oxygen furnished by the pond through the combined factors of absorption from the atmosphere and photosynthetic processes of plant life during the summer and winter conditions.

During the summer period the amount of oxygen required to satisfy the B. O. D. removal was 13.5 p. p. m. The difference between the D. O. in the influent and effluent from the pond was 3.1 p. p. m., which is considered utilized in the decomposition processes. This left 10.4 p. p. m. to be furnished by atmospheric absorption and photosynthetic processes.

During the winter period the D. O. required was 11.9 p. p. m. The difference between the pond influent and effluent was 2.1 p. p. m. which left 9.8 p. p. m. to be furnished by the factors just mentioned.

Thus the D. O. furnished through the agency of the pond was in p. p. m. practically the same for both seasons.

On the basis of pounds of oxygen supplied, the pond furnished during the summer period approximately 466 lb. oxygen per day. During the winter period 407 lb. per day were furnished or 87 per cent of that in the summer period. The greater amount of oxygen supplied by the pond during the summer period is probably due principally to the lower D. O. saturation in the pond during that season. According to Mahr[1] the difference in oxygen absorbed on the basis of average per cent saturation for the two seasons would be 1.0 gram per square meter per day. The actual amount

of D. O. furnished during these seasons was found to be 10.1 grams per square meter per day for the summer and 8.8 grams per square meter per day in the winter time or a difference of 1.3 grams per square meter per day.

It is of interest to compare here the amount of oxygen furnished by this pond on the basis of unit area, with observations derived from some investigations which Mahr points out.[2] These observations on oxygen furnished per unit surface area of streams or ponds as follows:

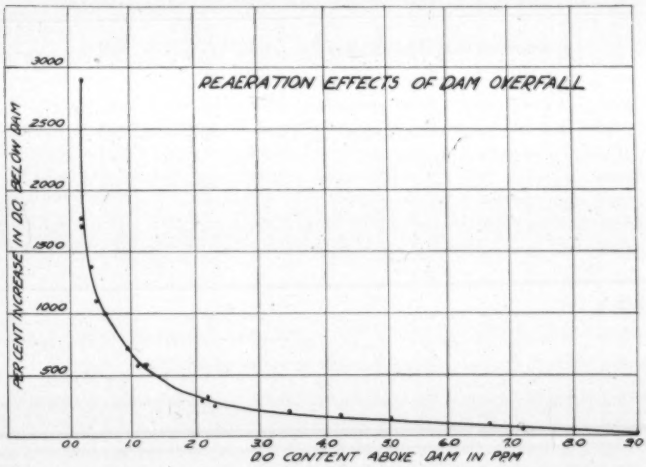

FIG. 5.—Relation of Increase in D. O. Saturation Below Dam to Initial Oxygen Content Above Dam.

Rhein	60% sat.	1.0 gm. per sq. meter per day
Fish ponds	30–40% sat.	2.0 gm. per sq. meter per day
Spree River	30–40% sat.	2.8 gm. per sq. meter per day
Landwehr Kanal	15–25% sat.	4.0 gm. per sq. meter per day

Similar observations on the Illinois River between Lockport and Chillicothe show an absorption capacity of 11 grams per square meter per day.

For faster flowing and well aerated streams this value may run as high as 30 grams per square meter per day.

In Figure 5 is shown the measured increase in oxygen saturation due to the overfall from the dam as related to the saturation deficit above the dam. This was compiled from D. O. determinations during this study on the water just before and just after passing over the dam.

Reduction in *B. Coli*

The reduction of *B. coli* through the pond is also shown in Figure 3. The death rate through the pond during the summer is quite rapid, showing a decrease of approximately 76 per cent between the point of pollution and the effluent from the pond. The percentage removal during the winter season was considerably less, amounting to only 40 per cent. This is quite in line with expectations that the death rate of these organisms would be considerably less under the colder temperatures.

Reaeration and Deoxygenation Coefficients of the Pond

It is interesting at this point to compare the coefficients for rates of equivalent deoxygenation and reaeration in the pond with those established by Theriault's investigations[3] for deoxygenation under incubated conditions and those used by Streeter[4] from studies on the Ohio and Illinois River.

The deoxygenation formulae proposed by Phelps and investigated by Theriault with respect to its validity is:

$$\text{Log}\frac{La}{L} = K_1$$

Where

La = First stage B. O. D. of sample,
L = B. O. D. of sample at time t,
K_1 = A deoxygenation constant or coefficient.

Theriault established the value of K, as 0.1 for incubation of recently polluted samples at 20° C.

Streeter used a mean value of 0.12 for K, as applied to his studies under summer temperatures.

Calculations with respect to the same formulae given above show that the value of K, for the summer with average temperature of 21° C., was 0.168 for the pond studied in this investigation. This shows a considerably higher equivalent rate of decomposition than either of the previously mentioned values indicate for incubated or river conditions.

If the value thus obtained for the rate of deoxygenation can be substituted in Streeter's formulae for saturation deficit[4]

Where

$$D = \frac{K L_a}{K_2 - K_1} \quad (10^{-k} - 10^{-k}) \quad D_a \times 10^{-k_2}$$

D_a = initial dissolved oxygen saturation deficit in p. p. m.
D = dissolved oxygen deficit after time t.
L_a = initial B. O. D.
K_1 = coefficient of deoxygenation and,
K_2 = coefficient of reaeration,

the value of K_2 or reaeration coefficient can be established for the pond. The average value of K_2 established by Streeter for the Ohio River was 0.24.

The value of K_2 or coefficient of reaeration for the pond during the summer period was found to be 0.26. The values for K_1 (0.168) and K_2 (0.26) thus obtained indicated that the natural reservoir storage in this case furnished an advantage over time of stream flow similar to that in the Ohio River, in that a greater rate of stabilization occurs simultaneous with equal or greater reaeration effects.

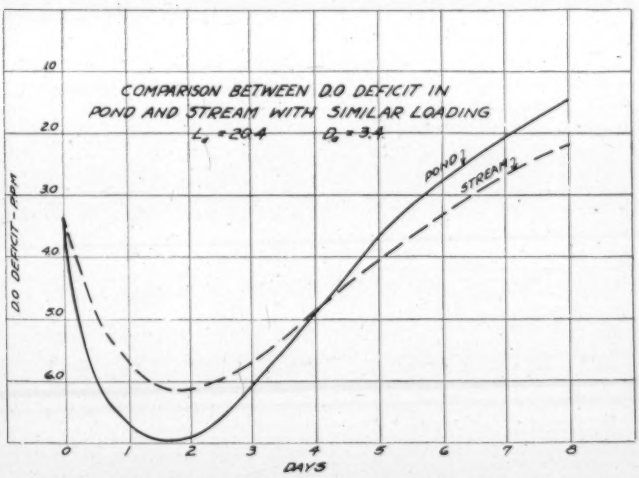

FIG. 6.—Comparison Between D. O. Deficit through Pond on Basis of Coefficients Determined Thereon, with D. O. Deficit in a Stream with Similar Loading.

The extent of these differences can be more readily seen in Figure 6 where the D. O. deficit through the pond is plotted for summer temperatures, using the K_1 and K_2 values just obtained as against a similar curve using the K_1 and K_2 values derived by Streeter for the Ohio River flow. The effect of the greater deoxygenation rate and slightly greater rate of aeration in the pond can be seen in the much greater D. O. deficit between one and two days, and in the more rapid recovery to normal after the fourth day.

Similar calculations for the winter conditions in the pond with average temperatures of 6.2° C. give 0.107 for K_1 or the coefficient of rate of

decomposition and 0.27 for K_2 the reaeration coefficient. It will be noticed that the coefficient of reaeration in the winter time was approximately the same as that in the summer time.

Calculated Benefits of Natural Stream Water Storage on Stream Purification

It is of interest in connection with these studies to observe the possible advantages of stream storage in a small pond similar to that available in this case over the natural purification that would occur in a stream following a normal course without such storage facilities.

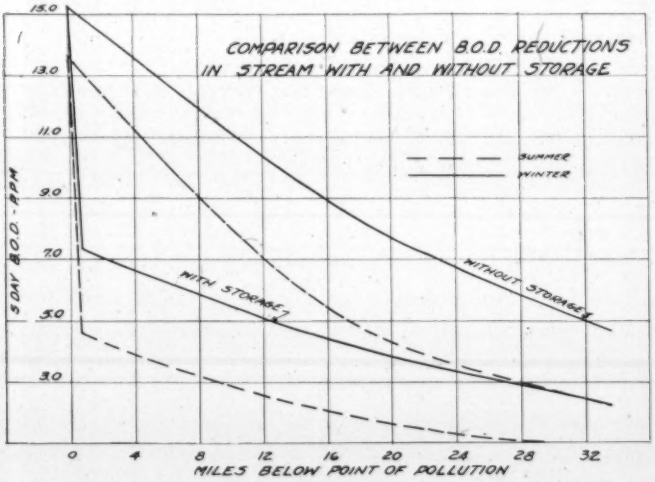

FIG. 7.—Comparison of B. O. D. Reduction in a Stream with and Without Natural Storage.

To show the value of such storage similar to that available in this case curves in Figure 7 have been drawn to show a comparison between the B. O. D. reduction in the stream upon which the previously discussed storage pond is located and the same stream with similar pollutional loading without storage.

The curve termed "actual" represents the 5-day B. O. D.'s at consecutive points on the stream with storage just below the point of pollution and is constructed in two parts. The initial rapid B. O. D. decrease between 0 and 0.33 mile downstream shows the actual decrease in B. O. D.

that occurred through the pond. From 0.33 mile on down the stream the curve is calculated for a deoxygenation coefficient of 0.12 and a reaeration coefficient of 0.24.

The "calculated" curve represents the same stream with similar pollutional loading but with no storage below the point of pollution and is developed from the coefficients just mentioned. The difference in B. O. D. between the two curves shows the continuous benefit at consecutive points downstream received from storage. These curves show that in the summer period with storage at an average temperature of 21° C. the B. O. D. of the stream below the dam at a point 0.33 mile down from the point of

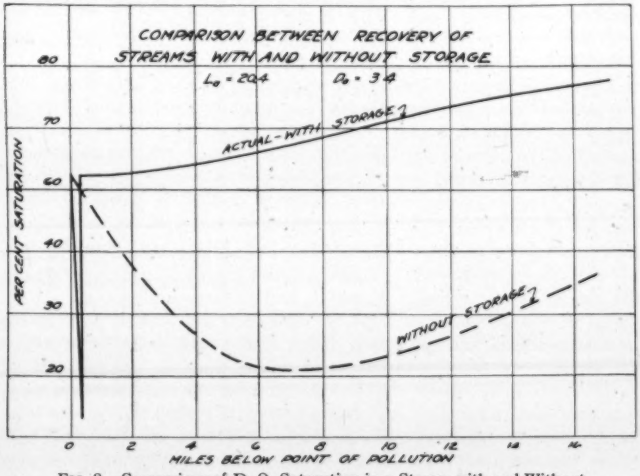

FIG. 8.—Comparison of D. O. Saturation in a Stream with and Without Natural Storage.

pollution was reduced to an amount which otherwise would not have occurred until after approximately 19 miles of normal stream flow. The reduction in the pond during the winter was less but was equivalent to approximately 22 miles of normal stream flow. This greater comparative reduction in the winter is due to the slower decomposition processes in a normal stream at low temperatures, but which, as previously discussed, did not apply to the same extent through the pond.

In Figure 8 the comparative curves have been constructed for dissolved oxygen deficit for summer conditions at consecutive downstream stages. The curves represent a more important picture than those for B. O. D.

in so far as detrimental effects on fish life and probability of nuisances are concerned. The calculated portions of the curves have been developed from the previously mentioned reaeration formulae with value of K_1 taken as 0.12 and K_2 as 0.24.

The curve representing the oxygen saturation deficit for the stream with storage has been constructed by taking the actual dissolved oxygen determinations in the stream from 0 to 0.33 mile downstream (below the dam) and from that point on the curve has been developed according to the above mentioned deoxygenation formulae.

While the coefficients used were developed for a stream quite dissimilar in dimensions, surface bed character and velocities from the stream involved in this study, the comparison is still effective since both curves are calculated on the same basis from 0.33 mile downstream.

The curves show that during the summer period the point of maximum oxygen saturation deficit is confined to a comparatively short distance below the outfall (0.33 mile) due to the storage provided in the pond instead of at a point six to eight miles downstream as would occur without storage. It is interesting to note that while the D. O. depletion in the pond is more extensive than would have occurred on the calculated basis had the flow followed a normal stream course without storage, the ratio of saturation deficit in the pond to that which would have occurred in a stream without storage is only $\frac{31}{23}$, or 1.35 times more saturation deficit in the pond than would occur at the maximum deficit point in a stream without storage. The saturation deficit in the pond is less than would be expected in view of the more intensive equivalent decomposition activities occurring therein. However, the comparatively large reaeration characteristics of the pond prevent excessive depression of D. O. saturation. The valuable feature of the storage is that at the point (7.0 mi.) where the maximum D. O. deficit would ordinarily occur in the stream without storage, the same stream with storage would be well on the road to recovery.

For instance, if a town were assumed to be located at a point six to eight miles downstream from a point of similar pollution shown, the maximum D. O. deficit would be coincident with the pollutional contribution of the town, making quite certain stream nuisances and destruction of fish life at points further down. Likewise additional pollution above the town would further depress the oxygen saturation at the same point. The pollutional load in this case would have caused approximately 69 per cent D. O. deficit in the summer time seven miles downstream and an additional B. O. D. load from the town equal to the load at the first point of pollution would further decrease the D. O. saturation deficit below the town to

practically zero. The action of the storage pond however would confine such an occurrence of D. O. depletion within a short distance.

Summary

Seasonal studies are compared to show the effect of a small impounding reservoir on the purification of a comparatively heavy sewage polluted stream. These studies show that the B. O. D. reduction through the reservoir amounted to 66.5 per cent in the summer time as against 52.5 per cent in the winter time. The average detention period of the pond during those seasons was 2.8 and 3.0 days, respectively. Average reduction in *B. coli* amounted to 76 per cent in the summer time as against 40 per cent during the winter season. Factors which might affect the relative reductions are discussed.

Figures are given showing the dissolved oxygen depletion through the pond, the dissolved oxygen furnished through the agency of the pond and the important reaeration effect of the overfall from the dam.

Coefficients for rate of deoxygenation and reaeration of the pond with respect to Streeter's formulae for deoxygenation of sewage polluted water under conditions of reaeration are determined. The coefficient of deoxygenation K_1 for the pond during the summer time amounted to 0.168 as against 0.1 determined by Theriault for incubated conditions and 0.12 used by Streeter for Ohio River conditions. The coefficient of reaeration K_2 for the pond amounted to 0.26 as against 0.24 established by Streeter for the Ohio River. Comparison of these coefficients shows more intensive equivalent decomposition effects in the pond than were found under incubated conditions or those used for river flow conditions. The reoxygenation through the pond was equally as great as under the compared river flow conditions and a considerably greater amount of D. O. was furnished by atmospheric absorption and photosynthetic processes than might be expected. Of the 13.5 p. p. m. oxygen consumed through the pond in the summer time 10.4 p. p. m. was furnished by the above processes. This amounted to 466 pounds per day. During the winter period approximately the same quantity of D. O. (9.8 p. p. m.) was furnished through atmospheric absorption and photosynthetic processes. In actual pounds, the pond provided during the winter period 407 pounds per day or 87 per cent of that provided in the summer time.

Curves are given showing the total reductions of B. O. D., *B. coli* and D. O. through the pond. Additional curves show the value of the impounding reservoir in purifying sewage polluted streams by comparing the curves based upon coefficients derived for this case with curves based upon coefficients determined from free flowing and non-impounded streams.

References

[1] F. Mahr, "Die Zulassige Belastung eines Gewassers durch Abwasser," *Technischen Gemeindeblatt*, **32** (1929).

[2] F. Mahr, "Die Zulassige Belastung eines Gewassers durch Stadtentwasserungen," *Technischen Gemeindeblatt*, **33** (1930).

[3] E. J. Theriault, "The Rate of Deoxygenation of Polluted Waters," *Public Health Reports*, **41**, 207 (1926).

[4] H. W. Streeter, "The Rate of Atmospheric Reaeration of Sewage Polluted Streams," *Public Health Reports*, **41**, 247 (1926).

Editorial

Water in Sludge

It is trite to state that the sewage disposal problem is primarily the problem of getting rid of the water contained in sewage solids. The dewatering of the solids is essential in any process of sewage treatment. Years ago the usual procedure was to dose the wet sludge with lime, filter press and dump. Digestion processes appearing later made it possible to dewater the solids on underdrained sand beds, which is still the generally accepted method. Recently the possibilities of mechanical dewatering have again been investigated.

There is a great need for more knowledge concerning the factors which control the water-holding properties of sewage solids, but as yet very little fundamental information is available. The work reported by Althausen and Buswell in this issue (p. 241) is directed toward the development of a mechanical method or procedure by which the water-binding properties of sludge may be studied, and the changes predicted under various types of treatment. It is a little disappointing to find that the proposed technique is still quite empirical and that arbitrarily prescribed conditions are necessary. However, it is too much to expect a completely satisfactory fundamental test at this time, but so much work remains to be done that any line of attack is welcome.

The technique proposed by Althausen and Buswell is not so simple nor cheap as the Büchner funnel tests used generally for estimating the filtrability of sludge, but the use of pressure rather than vacuum permits far greater range of conditions, with pressures varying from 100 to 3000 pounds. Further study is necessary to determine whether the pressure tests are suitable for general use.

The moisture content of sludge varies far more for differences in type (*i. e.*, Imhoff *vs.* activated) than for differences in source (*i. e.*, activated from Pasadena or Chicago). Likewise the moisture content after filtration is surprisingly constant at various places where the same type of filter is used. The production of a cake containing about 80 per cent moisture can be predicted almost invariably from conditioned activated sludge filtered on vacuum filters, whether it be at Milwaukee, Chicago, Pasadena or Houston; digested sludge, free from activated, filters to approximately 72 per cent moisture, whether at Baltimore, Columbus or Chicago; lime-precipitated sludge cake will average 60 to 65 per cent, whether filtered at Dearborn or elsewhere. Probably this uniformity is due to the use of

vacuum filters, limited as they are to less than 15 pounds per square inch; pressure filtration at Chicago has shown that, with pressures up to 100 lb. per sq. in., the moisture content of activated sludge cake falls in the range of 70 to 75 per cent and digested sludge around 62 per cent. Sludges in all cases were treated with ferric chloride.

The data presented by Althausen and Buswell indicate that even with enormous pressures of 3000 lb. in the Carver press, little improvement can be hoped for with untreated sludge by the use of higher pressures.

Sludge conditioning, or flocculation, has made filtration practicable. Without a conditioner, such as ferric chloride, ferric sulphate, alum or sulphuric acid, the filtration of activated sludge would be economically impracticable. It is unfortunate that this additional expense is necessary, but, on the other hand, fortunate that certain chemicals have been discovered which make filtration possible. Some possibilities still remain. For years the principle of "electroendosmosis," or use of an electric current for discharging assumed electrical charges during filtration, has intrigued sewage research workers, but as yet no practical use has been made of this "electric filter" for dewatering sludge.

A surprising theory of sludge conditioning has recently been put forth by Mr. Herbert D. Bell, of the Barnsley plant in England, as abstracted on page 174 of our January issue. Mr. Bell claims that the dewatering problem is physical rather than chemical, and he has reported that he has had marked success in improving drainage by adding to the sludge rough or sharp-grained inert material, such as a gritty clay or a sharp-pointed sand. Bell claims that (1) sharp and rough surfaces attract light solids suspended in an aqueous liquor and repel water, and (2) smooth and rounded surfaces attract moisture and repel solids suspended in an aqueous liquor. This is an astounding observation which will require further confirmation, but it illustrates the unexpected factors which may have to be taken into account.

No doubt there will be an epidemic of methods for chemical conditioning of sludge in the next few years, and probably some new conditioning materials will be discovered. While this development is occurring it is highly important that intensive study be devoted to the theoretical factors that determine the moisture-holding properties of sludge. It is gratifying that the Chemical Foundation, the sponsor of THIS JOURNAL, has helped to make possible some of this research. More extensive studies are urgently needed.

Employment Service

(1) DESIGNER thoroughly experienced in design and construction of sewage treatment plants. Just completed one year with general contractor on sewage treatment plant job. Previous four years drafting and design work in sanitary engineering. Total experience twelve years since graduation. Age 37. Married. Assoc. Mem. A.S.C.E.

(2) M.S. in SANITARY ENGINEERING, 1932, Michigan State College. Seven years with the Michigan State Highway Commission. Municipal engineering, including construction of water mains and sewers. Assistant instructor in sewage operators school. Publications on trickling filters and stream pollution. Age 31. Married.

(3) SANITARY ENGINEER, graduate M. I. T., four years experience in design of sewers and sewage treatment works, five years experience in investigating industrial wastes, designing and operating sewage testing stations, and investigating and developing methods and apparatus for sewage treatment. Three years as asst. supt. of large activated-sludge plant. Desires position to design or operate treatment works or to aid in the development of new processes and apparatus for sewage treatment. Age 36. Married.

(4) CHEMIST AND BACTERIOLOGIST, university graduate, six years superintendent of water filtration plant, past five years in sewage works laboratory, in charge of plant control. Recent experience in sludge filtration and disposal. Age 37. Married.

(5) SANITARY ENGINEER, M. I. T. graduate, 1927. Formerly connected with large sewage project, in responsible charge of plant operation and large-scale experimental investigations of separate digestion and disposal of sludge. Will accept job as engineer or sanitary chemist. Age 28. Married.

(6) SANITARY ENGINEER, M.S. from Michigan State College. Experience in highway and railway work. University work in soil bacteriology. Age 25. Single.

(7) SANITARY ENGINEER, Registered Professional Engineer in Pennsylvania. Six years with state board of health, seven years with prominent consulting sanitary engineers on sewage treatment plant design.

(8) SANITARY ENGINEER. More than ten years experience in designing, building and servicing mechanical equipment used in sewage treatment works, such as screens, clarifiers, digesters, aerators and pumps. Design and construction of paper mill and beet sugar factory. Age 37. Married.

Proceedings of Local Associations

NOTICE OF MEETING

The Spring Meeting of the New England Sewage Works Association will be held May 1, 1933, at the Blackstone Hotel in Woonsocket, Rhode Island.

F. W. GILCREAS, *Secretary-Treasurer*

Fifteenth Annual Meeting Texas Water Works Short School

Temple, Texas, Jan. 16 to 18, 1933

The Fifteenth Annual Texas Short School was held in Temple, Texas, on January 16, 17, and 18. Laboratory work was concentrated into the morning and afternoon sessions of the first day, making use of the local high school facilities. Although 58 attendants filled the small lecture room to capacity, the demonstrations were made by a staff which was able to adapt its performance to its audience. The morning session was about evenly divided between water bacteriology and sewage problems, which latter included a report of the committee on stream pollution. L. O. Bernhagen, Chairman of the Committee, made an oral report which recommended the adoption by law of lower limits for salt water allowable in fresh water streams and limiting the amount of pollution permitted from phenolic wastes or other injurious chemicals.

The luncheon and afternoon sessions were devoted to water problems.

The symposium on sewage scheduled for Monday evening lasted far into the night. W. S. Stanley, chemist at the new San Antonio activated-sludge plant, reported on observations at the plant covering a two-year operating period. Mr. Stanley called attention to the low solids content of various sludges obtained in the extreme South as a characteristic peculiar to the section and stated that attempts to thicken the sludges had disastrous results in digestion of the three kinds of sludge. (1) The primary tanks were fouled, a heavy scum formed and undigested material floated on the surface of the tank. (2) The activated sludge when thickened required an increased air supply which was too expensive. (3) The digested sludge was never satisfactory under sixty days.

Since it required sixty days to produce a satisfactory sludge, this figure was used as a basis for tank design. When taken with the factors of solids,

volatile matter, and population Mr. Stanley concluded that the digestion capacity needed in San Antonio is 5.5 cubic feet per capita, or 40 cubic feet per pound of volatile matter added per day.

Clyde C. Hays, chemist at the Waco plant, another recently installed activated-sludge layout, discussed the process of aeration, coagulation, clarification and oxidation which he is using.

Oral discussions followed on the use of activated carbon and ferric chloride in sewage treatment, also irrigation with sewage effluents.

The Tuesday and Wednesday sessions were concerned with various phases of water treatment.

At the business session which formally closed the meeting, the following officers were elected to assume their duties at once: D. T. Mauldin, Munday, Texas, *President;* Albert Davis, Austin, Texas, *First Vice-President;* L. C. Billings, Dallas, Texas, *Second Vice-President;* E. J. Elliott, Galveston, Texas, *Third Vice-President;* E. C. Johnson, Jacksonville, *Fourth Vice-President;* Mrs. M. Pierson, Austin, Texas, reëlected *Treasurer;* V. M. Ehlers, Austin, Texas, *Secretary;* Miss Ella G. White, Austin, Texas, *Editor of the Section publications.*

The registration totaled 145 and a number attended some of the sessions who did not register.

V. M. EHLERS, *Secretary*

The Fourteenth Iowa Sewage Treatment Conference and Sixth Annual Meeting Iowa Wastes Disposal Association

Ames, November 3, 4, 5, 1932

Superintendents of Iowa sewage works, city officials and engineers attended the Fourteenth Annual Fall Sewage Treatment Conference and the Sixth Annual Meeting of the Iowa Wastes Disposal Association at the Iowa State College, Ames. Members of the Association and guests totaled over seventy.

The program of the Conference included a number of excellent papers, organized discussions of problems of operation and supervision which were particularly helpful, and an inspection of the College Sewage Treatment Plant and experimental studies on garbage disposal and industrial waste treatment.

The first session of the Conference was called to order at 10:30 Thursday morning, Nov. 3, by Chairman Murphy. The Conference program then took up the formal papers, demonstrations, and Round Table Discussions as follows:

"How Far Can Natural Stream Purification Be Utilized?" by Wm. E. Stanley.

"What About Government Finance for Municipal Sewage Works?" by C. H. Currie.

"The Use of Sewage Gas to Incinerate Garbage," by Perry LaRue.

* * * * *

"What Is a Good Sewage Works Effluent?" by A. H. Wieters.

"The Why and How of Satisfactory Sewage Tank Operation," by F. H. Austin.

"The Operation of the Sibley Sewage Works," by E. E. Truckenmiller.

"Securing Public Interest and Support," by H. R. Green.

* * * * *

"Industrial Wastes and Their Effect on Sewage Works Operation," by L. F. Warrick.

"What Can Be Done About Creamery Wastes?" by Max Levine.

"Recent Studies on the Disposal of Corn Cannery Wastes," by W. E. Galligan.

Round Table Discussion on Operators Problems.

* * * * *

"How to Get Better Filter Operation," by W. E. Galligan.

"Chemical and Physical Characteristics of Sludge," by Jack J. Hinman, Jr.

"Control Methods for Plant Operation," Laboratory Instruction by Wm. R. Mark, Jr., and Benjamin A. Whisler.

* * * * *

"Sewage Works Operation During the Depression," by Earle L. Waterman.

"Operation Suggestions for Small Plants," by Paul J. Houser.

"Diffuser Mediums for the Activated Sludge Process," by Frank C. Roe.

"Plant Control Practices," Laboratory Instruction in charge of Wm. R. Mark, Jr., and Benjamin A. Whisler.

On Friday evening the Annual Dinner of the Iowa Wastes Disposal Association was held. Following the food and entertainment a pseudo scientific discussion on, "What People Drink," was humorously presented by Jack J. Hinman, Jr.

The Annual Business Meeting of the Association was called at 8:00 P.M. Friday evening, with President Max Levine in charge. After the

reports of officers and committees, and the business of the evening, officers were elected. They are as follows for 1933:

President, Max Levine, Ames; *Vice-President*, Earle L. Waterman, Iowa City; *Secretary-Treasurer*, L. J. Murphy, Ames; *Directors*, Geo. A. Nelson, Boone, E. E. Truckenmiller, Sibley; *Representatives to the Board of Control of the Federation of Sewage Works Ass'ns*, Max Levine, Ames; W. E. Galligan, Ames.

Adjournment followed.

LINDON J. MURPHY, *Secretary*

California Sewage Works Association
Notice of Fifth Spring Conference

Friday, May 5

The Fifth Spring Conference of the California Sewage Works Association will be held May 5 and 6, 1933, at San Luis Obispo. The program includes visits to the sewage treatment works at San Luis Obispo, Arroyo Grande and Prismo Beach. The following papers are scheduled:

1. Chemical Precipitation—Symposium.
   - *a.* History, Leon B. Reynolds.
   - *b.* Palo Alto Experiences Summarized, Ralph A. Stevenson.
   - *c.* What Others Are Doing, Charles Gilman Hyde.
2. Incineration of Screenings, Skimmings and Sludge, J. J. Jessup, A. P. Banta and R. F. Goudey.
3. Hazards—Symposium.
   - *a.* Cross Connections Between Water and Sewage Systems, Dr. Carl Wilson, R. L. Derby and C. W. Sopp.
   - *b.* Detection and Measurement of Gases, S. H. Ash (U. S. Bureau of Mines).
   - *c.* Hazards, Gas Masks and First Aid, Carl Fry (Supt. of Safety, Industrial Accident Commission), F. D. Bowlus and Fred West.

Saturday, May 6

1. Changes in Character of Sewage, W. A. Allen, F. S. Currie and W. C. Roberts.
2. Keeping Power Bills Down, Mr. Thomas (General Electric Company), H. K. Palmer and A. W. Wyman.
3. Tax Delinquencies in Sanitary Districts, C. R. Compton, D. E. Perry and G. C. Zuckweiler.
4. Design of Gas Lines and Holders, T. R. Haseltine. Discussion by C. C. Kennedy, H. B. Hommon and M. L. Crist.
5. Law on Liability for Sewage Disposal, Hugh Gordon (Los Angeles Co. Sanitation Districts). Discussion by B. J. Pardee.

Reviews and Abstracts

H. W. STREETER

Interceptor and Sewage Disposal Works, Fort William, Ont.

By R. O. Wynne-Roberts

Canadian Engineer, **63**, 17 (December 13, 1932)

Local nuisance led to the construction of intercepting sewers and sewage treatment works to serve part of Fort William in 1931–32. The sewer was built as a relief measure.

The interceptor was designed for three times the dry weather flow. It was built of vitrified clay pipe. Because of foundation conditions, a timber cradle was provided, the pipe was imbedded in concrete and the joints covered with canvas. The project included three syphons built as duplicate lines of 6-inch cast iron pipe. The syphons were laid by means of water jets and lead joints made under water. Regulator manholes include aluminum backwater flap-valves and V-notch weirs for the diversion of dry weather flow.

Present treatment of the sewage includes sedimentation and separate sludge digestion with prospect of later extension to the activated-sludge process. Sewage is coarse screened and then lifted by electric driven pumps which are provided with duplicate sources of power.

The two settling tanks are 35 feet square, $14^1/_2$ feet deep at the center, and are equipped for center feed and peripheral flow. Hankin-Fiddler double spiral scrapers are included. Sludge is removed by a pump which is automatically controlled by the sludge level.

A single digestion tank is 35 feet square, 12 feet 4 inches deep (side depth). The bottom slope is fairly flat. The cover is a fixed concrete cover which has a gas dome. The tank contents are heated to 80° F. The heating coils are 2-inch galvanized steel and the circulating pump is a 10 g. p. m. unit.

Sludge storage for the winter is provided by a concrete tank 35 feet long, 28 feet wide by 10 feet deep. This tank has removable wooden covers.

Three sludge drying beds each 60 feet by 30 feet are provided.

Frank Tolles

Factors in the Production of Methane Gas from Sewage Sludge

BY R. O. WYNNE-ROBERTS

Canadian Engineer, **64**, 25 (January, 1933)

This paper was read at the annual (1932–33) convention of the Canadian Gas Association.

Separate digestion of sewage sludge at 75–80° F. is accomplished in 30 days. It yields four times the volume of gas produced from digestion at 45–50° F. which requires four months. At the higher range the yield of gas may reach over 1 cubic foot per capita but the average is less.

Operating procedure at small plants is to withdraw sludge perhaps once daily and then to fill with fresh solids. This results in irregular production of gas. At seven plants of such kind the gas recovered is not sufficient for heating requirements and small coal or natural gas boilers are used to supplement the sewage gas.

Methane is slow burning. The ignition velocity may be as low as $6^1/_2$ feet per second. If sewage gas and coal gas are mixed it should be with the coal gas predominating—say 5 to 1—to avoid undue reduction of flame velocity. Natural gas burners are suitable for sewage gas.

The composition of sewage gas from digesters is:

Location	Constituents—Per Cent						B. t. u. per Cu. Ft.
	CH_4	CO_2	H	N	H_2S	O	
Pearson, Ill.							
Buswell	63.4	31.3	1.6	3.7			
Halle, Germany	69.8	29.0		1.1	0.1		732
Birmingham, Eng.	67.0	30.0		3.0			625
Essen, Germany	68.0	28.4		3.4		0.2	
Munich, Germany	70.0	30.0					715
Baltimore, U. S. A.	70.5	26.5		2.8		0.2	707
Toronto, Canada	58.5	28.0	3.7	8.0 (Diff.)		1.8	602

The paper refers to W. H. Fulweiler's paper in THIS JOURNAL **2**, 425 (July, 1930). FRANK TOLLES

Water Supply of Delaware County Menaced

BY HARRY M. FREEBURN

Civil Engineering, **2**, 756 (December, 1932)

The article as titled is based upon a paper presented at the October 6th meeting of the Sanitary Division, American Society of Civil Engineers.

It recounts the efforts which have been made to control the pollution of an important stream which traverses a populous area.

The Delaware River is boundary to Delaware, New Jersey and Pennsylvania. Among the larger communities riparian to the lower river are Philadelphia, Camden and Chester. Delaware County is located downstream from Philadelphia. It includes 47 civil divisions and has a population of 1515 per square mile—280,000 in all (1930). Chester, the largest city, has 59,000 people.

At Chester the Delaware River is tidal. In this vicinity it receives the flow of many small streams each of which contributed its load of untreated sewage. Nuisance prevailed and the Chester water supply from the river was affected.

Correction of conditions was begun by the Pennsylvania State Department of Health in 1907 through orders to Philadelphia to eliminate the pollution of one of the streams tributary to the river. Adjoining Delaware County communities participated in this improvement which looks eventually to treatment at the proposed Southwest Works of the City of Philadelphia.

In 1928, and following remedial measures instituted by the City of Chester, the effort was extended by obtaining joint action of 34 Delaware County municipalities. Representatives formed an unpaid engineering board which developed a project of improvement in terms sufficiently detailed to enable coördinated action. This effort affects some 65 square miles of area and will involve a comprehensive system of collecting sewers, pumping stations (9) and treatment works (5).

Trunk sewers were designed for 1980 conditions on the basis of an average flow of 133 g. c. d., a maximum of 233 g. c. d. and infiltration at 2000 gallons per acre daily.

Provisions for two of the plants which will discharge into a creek call for secondary treatment. The remaining plants will provide for the removal of settleable matter, this being in accord with a 1922 agreement between Pennsylvania and New Jersey relative to sewage discharge into the Delaware River. One of the latter works will also provide disinfection as a measure protective of the Chester water supply.

Construction costs were estimated at $7.50 to $15.00 per capita for primary treatment, and $15.00 to $25.00 for works which include secondary treatment. The total cost was estimated at:

Trunk Sewers	$1,783,000
Pumping Stations	232,000
Force Mains	149,400
Treatment Works	2,852,000
Total	$5,016,400

Sewer repair was taken at $6.00 to $12.00 per mile per year, and cleaning at $15.00 to $25.00 per mile per year.

Water supply problems of the lower Delaware River have been met in part by enlargements accomplished or proposed for supplies which are obtained from tributary streams. At Chester, which uses river water, considerable work has been done to combat the effects of increasing pollution, industrial wastes and added salinity. The *B. coli* index ranged during recent years from a minimum monthly mean of 27,400 per 100 cc. to a maximum of 601,300. The industrial wastes are many and complicated. Corrective work has included pre-chlorination, aeration, activated carbon-filters and dosage with activated carbon and bleaching clay. The substitution of an up-river supply is indicated as the eventual solution.

FRANK TOLLES

Sewage Disposal for Coast Resorts

BY C. G. WIGLEY

Civil Engineering, **2**, 743 (December, 1932)

The article deals with sewage disposal for New Jersey coast resorts and was prepared from a paper presented at the October 6, 1932, meeting of the Sanitary Engineering Division, American Society of Civil Engineers.

Particular factors in the disposal problem are (1) a summer-time peak population 10–15 times the normal, (2) moderate elevation above sea level, and (3) protection to bathing beaches and shell fish beds.

Sewers are built on flat grades—as low as 0.001—to conserve cuts and pumping. Foundation in wet sand is often provided by planks and sometimes also by short hand-driven piles. Pipe sewers so built often crack under motor truck traffic. Joints for wet work consist of heated pitch and portland cement mixed half and half to form a putty. The joining material is used while warm and is then chilled with water or wet sand.

Sewage treatment almost universally consists of (*a*) sedimentation, (*b*) disinfection, and (*c*) discharge at least 1000 feet off-shore (18–22 feet water) In some cases the tanks are built underground and are ventilated by flag poles 50–75 feet high and open at the top. The tanks at Asbury Park are fan-shaped; they show a good removal of the finer solids. Settling tanks at Atlantic City have four hoppers from which sludge is drawn daily to a baffled concentration tank. Also, at Atlantic City the growth of molds on the drying sludge is encouraged. Sludge is sold for fertilizer (see Abs., THIS JOURNAL, **3**, 755).

The article also alludes to State Health Department investigations with conclusions as follows:

(1) Sewage and salt water do not mix *readily*. Discharged sewage rises to form a spreading film the movement of which is responsive to surface currents. Sampling is difficult.

(2) Chlorination of tank effluent resulted in a reduction of *B. coli* in surf samples from 21 per cc. to less than 1 in 5 cc.

(3) "...where data are obtained from large population groups, there is apparently a relation between the number of cases of typhoid and paratyphoid fever and the pollution of (bathing) beaches." The effect of such pollution is regarded as selective rather than generally epidemic.

Discussion.—Clyde Potts (*Civ. Eng.*, **3,** 95) suggests that pollution at bathing beaches may be due to the bathers. Mention is made of the ventilation of covered tanks by means of a vent fan and a flag pole stack, 18 inches in diameter at the base, 12 inches at the top and 75 feet high. Present ocean outfalls are of universal jointed cast iron pipe.

Discussion.—Almon L. Fales (*Civ. Eng.*, **3,** 95) states that from the standpoint of numbers exposed, frequency of exposure and the quantity absorbed, the danger of infection from drinking contaminated water is much greater than that from bathing in such water. This leads logically to a standard for bathing waters which is lower than that for drinking water. It does not, however, justify pollution; visible sewage pollution should not be tolerated and waters "should be maintained reasonably free from bacteria of known sewage origin." In a given case, standards for bathing waters will "be based on the source, character, and amount of pollution and on the results of chemical and biological examinations correlated with the results of bacterial analyses." FRANK TOLLES

Joint Trunk Sewers for the Hackensack District, New Jersey

BY GEORGE W. FULLER

Civil Engineering, **2,** 763 (December, 1932)

The article in *Civil Engineering* is based upon a paper presented at the October 6th meeting of the Sanitary Engineering Division, American Society of Civil Engineers.

The Hackensack Valley includes about 209 square miles and a population of about 500,000. The upper part of the water shed is used for water supply.

Part of the area is served by 40 municipal sewage treatment plants, many of which are overtaxed. The lower portion of the valley has but a few treatment plants. The tidal section of the river is polluted seriously, and is in places offensive, and such as to affect recreational facilities.

Remedial measures were initiated through an enabling (state) act in 1926 and followed by the creation of the Hackensack Valley Sewerage District in 1930. A Sewerage Commission was organized in 1931 by Hudson and Bergen Counties.

The findings of the Sewerage Commission favored a joint trunk sewer, and, in order to minimize pumping, two district treatment plants. Local plants were recommended for the Palisades area. The two district plants have been located one (Droyers Point) near the mouth of the river, and the second (Little Ferry) in the meadows at about the mid-point of the county. Some of the existing individual plants will be continued in use for a time.

Northerly (Little Ferry) Works.—The sewerage is separate. Trunk sewers were designed for population 30 years hence and having an average flow of 115 g. c. d. and a maximum of 293 g. c. d. The latter is equivalent to more than twice the average domestic rate, about twice the average industrial rate and more than three times the average infiltration.

Treatment works were designed for 1947, 392,000 people and 45 m. g. d. Estimates of cost were based upon an activated sludge plant which included coarse screens, detritors, preliminary clarifiers (1 hour) detention aeration tanks (5.6 hours detention with 25 per cent sludge return), reaeration tanks (4 hours) and final clarifiers ($2^1/_2$ hours), separate sludge digestion tanks (3.0 cu. ft. per capita plus storage at 2.1 cu. ft. per capita) and sludge drying beds (0.6 sq. ft. per capita).

Southerly (Droyers Point) Works.—The sewerage is combined. Trunk sewer design was based upon an average flow of 120 g. c. d. and a maximum of 310 g. c. d.

Treatment works (285,000 population, 34 m. g. d.) were designed for an activated sludge plant as in the case of the northerly works, but sludge disposal capacities were increased one-third to meet the increased solids from combined sewers. It is thought that active design of the southerly plant, which adjoins Newark Bay, may be preceded by a consideration of the use of chemicals as at Dearborn.

The mechanical dewatering of sludge and burning with or without garbage, etc., has been studied. Also, thought was given to methods of partial treatment intermediate between sedimentation and the activated-sludge process.

Costs and Financing.—The total cost to a 1929 base, including easements but exclusive of interest during construction, was estimated at $20,000,000 for that part of the work needed until 1947. Extensions good till 1960 would cost about $4,400,000.

The construction cost, according to recommendations, would be divided between the counties in a fixed ratio. Operation, maintenance and capital charges would be prorated to the municipalities on the basis of measured

flow and each will determine for itself the plan for ultimate assessment—rentals, taxes or both.

The Sewerage Commission is now trying to establish a program for establishing contract arrangements with the several municipalities.

Abstractors' Note: A description of the foregoing project has been embodied into a comprehensive printed report entitled "Report of the Hackensack Valley Sewerage Commission—Bergen County and Hudson County, New Jersey, 1931." (Reviewed in THIS JOURNAL, **4**, 399 (March, 1932).)

FRANK TOLLES

Dutch Government Institute for the Purification of Waste Waters, Annual Report—1931

BY H. KESSENER

The institute gives advice, makes plans and specifications for cities, towns, industries, etc., upon request of the Ministry of Labor, Commerce and Industry, helps to place in operation new installations and controls the operation. The second function is to make scientific studies dealing with the purification of waste waters and stream pollution. Results can be published only with consent of the Ministry of Labor, Commerce and Industry. In general the institute does not consider that water pollution is a local matter, but is viewed in connection with all sources of pollution, the creation of nuisance, or the use of the water for potable, industrial and recreational purposes. This policy has found more and more favor by the authorities, industries, groups and individuals.

Descriptions are given regarding advice on pollution, plants in operation at institutions, dairy wastes, laundries, slaughter and packing-houses, glue factories, textile, fish drying and pickling liquors. Results are given of the operation of trickling filters at two institutions and three slaughter-houses. The two institutional plants are very similar and consist principally of settling basins and trickling filters (filled with high pressure slag about 5 ft. deep) and equipped with a rotary, spray device. Sludge collected in the humus tanks (Dortmund type) is mixed with garbage and composted. Average results obtained from the filters at the different plants are as given in Table I.

The filters of the sanatorium have an area of about 3000 sq. ft. (No figures are given of the load placed on the filters. The settled sewage has a high B. O. D. and the effluents extraordinarily high amounts of nitrates. Under American conditions filters of this size would take care of about 150,000 to 175,000 gal. per 24 hr. of settled sewage. Assuming that the sewage produced is 50 gal. per capita per 24 hr., the strength of the sewage would correspond very closely to that of a number of New Jersey institu-

TABLE I

AVERAGE RESULTS OF INSTITUTIONAL AND SLAUGHTER-HOUSE TRICKLING FILTERS (IN P. P. M.)

	Sanatorium, Apeldoorn		Asylum, Vught		Slaughter-house, Lobith		Slaughter-house, Twello		Slaughter-house Schagen	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
Susp. Solids	61	....	208	...	226	...	275	....	241	....
Vol. Susp. Solids	56	....	171	...	208	...	..	....	183	....
B. O. D. (5-Day)	204	6	372	9	1506	45	1251	58	447	42
Ox. Cons. (10 min. boiling)	97	15	190	33	733	80	591	121	300	101
Total N	50.7	30.5	85	59	235	92	214	87	108.7	72.6
NH_3	47.2	6.1	75	4.3	155	14.6	141	56	78.7	26.6
NO_2	...	0.35	...	2.0	..	6.0	..	5.2	....	7.9
NO_3	...	106.0	..	118.0	..	285.0	..	90.7	....	139.7
Total Alk. (CaO)	114	7	298	97	452	262	422	195	769	626
Cl	73	72	112	100	186	187	1470	1657	4395	4050

tions which have on an equivalent volume basis of 50 gal. per capita per 24 hours from 600 to 800 p. p. m. B. O. D. and correspondingly lower in the settled sewage. See Ridenour, THIS JOURNAL, Nov., 1932. The reduction in alkalinity is probably due to disappearance of ammonium carbonates.—*Reviewer.*)

Much practical experience has been obtained in the treatment of slaughter-house wastes. These wastes, containing large quantities of blood and fats, can be treated either by settling and trickling filters or activated sludge. In some cases broad irrigation has been practiced. Primary treatment must be provided so that most of the hair, fats and coarser material does not reach the secondary treatment devices. The concentration of wastes received from packing-houses is greater than from city abattoirs on account of more rapid methods of handling and less use of wash water. The primary treatment must consist of efficient settling and grease removal in such a way that the material is kept as fresh as possible. Activated sludge as secondary treatment is preferable on account of absence of odor and flies. The systems operating at Lobith and Twello, where the primary treatment consists of screens, settling and grease removal, followed by trickling filters, show remarkable good results (Table I). The settling and grease removal at Twello is obtained by a series of three tanks through which the material is carried. The first is a settling tank of the Dortmund type, followed by two parallel basins with horizontal flow and again followed by two settling tanks. The settled sludges are pumped regularly into tank cars and used as fertilizer. In the Twello slaughter-house from 500 to 600 hogs and some calves are killed daily.

The trickling filter is about 7 ft. high with a diameter of 40 ft. Discharges on the filter are very irregular, with little during the morning and the maximum in the late afternoon.

A complete plant has been put into operation for the city of Winterswijk, which has at least one novel feature, namely, that the digestion tanks (gas collection) are equipped with paddles, similar to those used in the Imhoff type of aeration units for activated sludge (Figure 1). The paddles rotate slowly and are designed to mix the fresh solids with the ripe sludge and prevent scum formation.

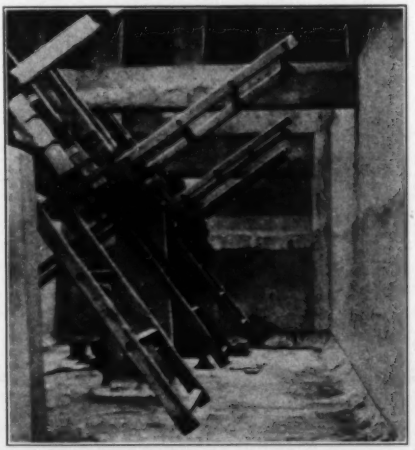

Fig. 1.—Digestion Tank at Winterswijk Equipped with Paddles.

The slaughter-house waste at Beverwijk is treated by the surface aeration (brushes) activated-sludge process. Analyses of the average influent to the aeration unit gave the following results, in parts per million: suspended solids 350, B. O. D. (5 day) 1812, total nitrogen 325, ammonia 228. The reduction amounted to: B. O. D. 98 per cent, total N 34 per cent, and ammonia 96 per cent; nitrites and nitrates in the effluent were 5.4 and 99 p. p. m., respectively. Power consumption in kw. hr. were: motor 180, gears 137, three brushes 19, aeration and sludge return 249, total 585 kw. hr. For continuous efficient results a total of 550 kw. hr. has been found sufficient.

At Hilversum experimental activated sludge plants were built, one according to the Imhoff system, with submerged contact aerators and diffuser plates and paddles in the aeration tank; the other according to the Kessener system with brushes and paddles in the aeration tank (Figures 2 and 3). The Imhoff aeration tank had a capacity of 70,000 gallons and the Kessener tank of 63,500 gallons. Operation was conducted in accordance with the personal instructions of Imhoff and Kessener. After somewhat more than $1^1/_2$ years' operation, the author summarizes the results as follows: "The economical interpretation of the results obtained on the basis of 5 day B. O. D. lead to the conclusion that the Kessener installa-

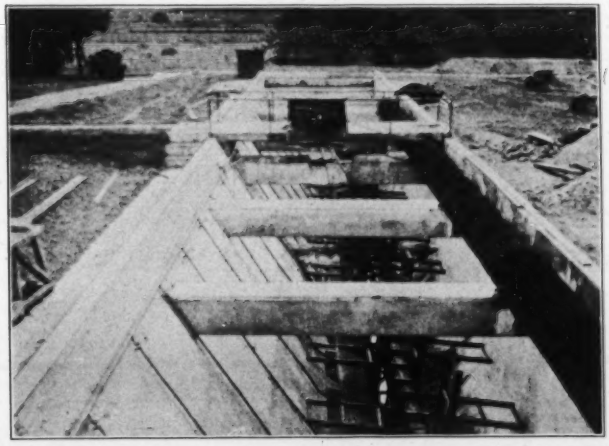

FIG. 2.—Aeration Tank at Hilversum Equipped with Paddle Wheels, Diffused Air and Brushes (Kessener System).

tion was preferable, since the Imhoff installation required 42 per cent higher operation costs with 26 per cent greater efficiency If the conclusion is based upon the oxygen consumed (10 min. boiling) the relative value of the Kessener device is still greater, since the purification of the Imhoff system was only $12^1/_2$ per cent greater. If the Imhoff submerged contact aerator was placed out of operation the yearly operating cost was reduced by 24 per cent, but the purification as measured by the 5 day B. O. D. was reduced 34 per cent and on the basis of oxygen consumed about 12 per cent. According to the latter calculations there is no economic value in the submerged contact aerator, but according to the former (B. O. D.) there

would be, although not sufficient to counterbalance the considerable complication of operation which the addition of this device requires. It is possible that the advantage of the pre-aeration device was due to removal of easily decomposable materials which affect the B. O. D. values greatly." The sewage treated contained considerable quantities of industrial wastes (chemical industries, ink, textile, pickling liquor, etc.).

Studies were made to determine the "purification capacity" of an activated-sludge plant with regard to a given sewage. The purification capacity of an activated-sludge plant is considered to be the grams oxygen demand that can be satisfied hourly in one cubic meter of aeration tank in

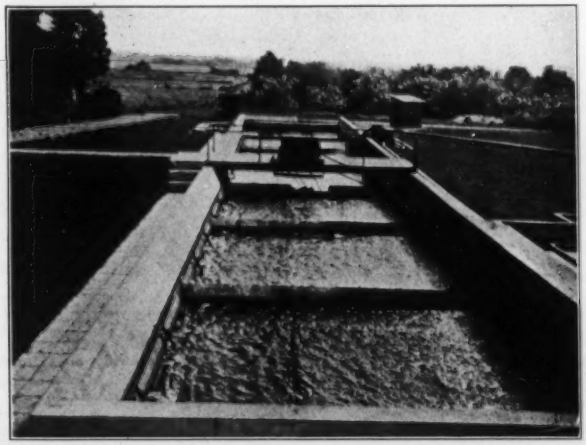

FIG. 3.—Kessener Brushes in Operation at Hilversum.

order to maintain a stable effluent, or expressed differently the parts oxygen required per million parts tank capacity per hour to produce a stable effluent. The different determinations to be made and the type of analyses deemed essential are for influent: B. O. D., oxygen consumed (10 min. boiling) and for effluent: B. O. D., oxygen consumed, methylene blue, nitrites and nitrates. The "limit of lability" of an effluent is defined as the state of purification at which nitrification begins and further by the decolorization of methylene blue after a given time when no NO_2 or NO_3 are present. For presentation of the analyses to determine the "purification capacity" and "limit of lability" of purification the results are plotted so that one line indicates the oxygen demand and another denotes the quality

of the effluent (methylene blue tests, NO_2 and NO_3 determination). The latter line may be on both sides of the line indicating the "limit of lability." The two lines coincide when the methylene blue stands up for 96 hrs. at 27° C. and no NO_3 or NO_2 are present. Under the line are the zones which show increasing putrescibility. The zones are indicated by the quantities of oxygen in the form of NO_3 required to prevent decolorization of the methylene blue. Above the "limit of lability" line are the zones of increasing nitrification. It should be taken into consideration that the results obtained on one day are affected by the efficiency of the process on the previous day. The average results plotted will show the average purification efficiency.

The author states that "the activated-sludge process owes the advantage of a sharp demarcation of the "limit of lability" to the homogeneity of its purification agency and to the mutual independency of detention period and aeration intensity. This advantage results in accessibility to systematic research and theoretically in an economical priority over purification processes by means of percolating filters or irrigation."

The report closes with a series of detail drawings of the several plants constructed and placed in operation. WILLEM RUDOLFS

The Use of Fine Screens in Settling Tanks

BY R. WELDERT AND P. SANDER

Gesundh. Ing., **56**, 7 (1933)

The treatment plant of the city of Eberswalde consists of Kremer type settling tanks and sprinkling filters with secondary settling tanks. The sewage, averaging 740,000 gallons per day, passes through bar screens and grit chambers. The preliminary purification consists of two connected settling tanks with horizontal flow, located over the five Kremer sludge tanks. Each tank is 82 feet long and 16.5 feet wide. The depth of the water to the sludge hoppers is about 8 feet and the settling capacity of each tank is about 10,000 cubic feet. More than 95 per cent, by volume, of suspended solids are removed. This performance is considered very good, especially when it is considered that the sewage has already passed through a Riensch-Wurl screen having 2-mm. openings, which removes about 4 cubic yards.

In December, 1931, experiments were started to determine the value of fine screens in connection with settling tanks. In carrying out the experiment two small screens, each having a surface of about 80 square feet, were placed over the fourth and fifth sludge tanks. The calculated

velocity through the tanks is about 0.1 inch per second and through the screen about 0.15 to 0.24 inch per second. A large number of samples were collected and an average of their analyses is shown in the table.

THE EFFECT OF FINE SCREENS ON REMOVAL OF SUSPENDED SOLIDS

EXPERIMENTAL RESULTS OF RAW AND PURIFIED SEWAGE.

Date	Sewage Flow, Cu. Ft. per Day	Temperature of Air, °F.	Screened: Suspended Solids, P. p. m.	Screened: Chlorides, P. p. m.	Screened: Temperature of Water, °F.	Unscreened: Suspended Solids P. p. m.	Unscreened: Chlorides, P. p. m.	Solids Removed by Screen, %: Suspended	Calculated Amount of Solids Removed Daily as Pounds Dry Solids: Suspended
12/29/31	86,500	38	36	134	48	49	60	134	40.0	130
1/7/32	111,000	43	83	162	48	48	119	154	30.3	250
1/14/32	89,200	..	104	154	..	..	154	162	32.5	279
1/21/32	85,700	31	47	162	48	49	74	162	36.5	144
1/29/32	83,800	32	53	160	47	48	87	160	39.1	178
2/15/32	82,200	37	55	158	46	46	80	158	31.3	128
Average	89,800	36	63	155	47	48	96	155	35.0	185

There was no explanation of the fact that the temperature of the sewage in the section without the screen was always a few tenths of a degree higher than in the section with the screen. The suspended solids were determined by filtering, with suction, one liter of the sample through a glass tube 0.3 inch in diameter and about 2.4 inches high, filled with wads of cotton. After filtering the tubes were washed with distilled water, dried 6–8 hours at 110° C. and weighed. This method removed only the actual suspended solids and not, as in filtering through asbestos, a considerable portion of the colloidal material. The volumetric analyses of the suspended solids were also made but were not considered reliable because of the small volumes to be read. Samples were also analyzed for chlorides and oxygen consumed. Chloride content of both samples was approximately the same but the oxygen consumed was always smaller in the screened sample than in the unscreened one. It was found that hydrogen sulphide formed about an hour sooner in the screened tank than in the unscreened one. This is due to the fact that the screened sewage contained much smaller particles, which became septic rapidly and that the sewage was inoculated by the sludge growing on the screen. The screens were not disturbed until February 15, when the experiments were concluded. It was then found that there was a bright green odorless sludge layer about 0.6 inch thick on the front of the screen. On the back of this screen there was a thinner layer of the same sort of sludge.

The experiments have shown that properly operated fine screens can

increase the efficiency of settling tanks already working satisfactorily. It was found that sewage settled and screened contains about one-third less of suspended solids than that merely settled. G. P. EDWARDS

Gas Production and Utilization at the Municipal Treatment Plant at Blankenburg (Harz)

BY DR. WEILICH

Gesundh. Ing., **55**, 485 (1932)

The sewage treatment plant consists of mechanical settling tanks, separate-sludge digestion tanks, sprinkling filters and secondary settling tanks. The cylindrical sludge-digestion tank has a depth of 28.7 feet, 8.7 feet of which is below the ground level, and a diameter of 26.6 feet. It is divided into two parts by a vertical partition in which there are two rectangular openings about 8 feet from the floor so that sludge can flow from one part to the other. As sludge is added to one section, supernatant liquor is drawn off from the other. By adding the sludge first to one tank and then to the other, part of it passes from one tank into the other so that the sludge is well circulated. The digested sludge is drawn off from the bottom by hydraulic pressure. The digestion tank has a fixed cover with two iron gas domes for the collection of gas. The digestion tank is heated with two copper heating coils. Although the sludge cannot be heated uniformly throughout the tank because of the lack of sludge circulation, gas formation has been very satisfactory, averaging 2800–3500 cubic feet daily. The gas is purified and pumped into two gas containers, each with a capacity of 175 cubic feet. Although, during cool weather, gas is used for heating the digestion rooms, the main part of the gas is used for operating purposes. Originally electricity obtained from the city provided power and light but a gas motor has been procured to run a generator, which furnishes the electricity for all power and light needs. This gas motor furnishes eight horsepower in continuous operation and requires about 113 cubic feet of gas per operating hour. The plant has operated continually since June, 1931, and has proved satisfactory. Although gas is used for heating the office, machine room and the attendant's house and to provide all the power light and heat required at the treatment plant, there is always an excess so that some must be allowed to escape in the air. It is intended to add sludge circulating equipment so as to hasten sludge digestion and to increase gas production. G. P. EDWARDS

The Biological Treatment Plant at Erfurt

BY DIPL.-ING. STADE

Gesundh. Ing., 55, 499 (1932)

Early in 1931 a paddle wheel activated-sludge plant was put into operation at Erfurt to supplement the treatment by Imhoff tanks already in existence. Erfurt has a population of about 140,000 and covers a territory of about 12,000 acres of which about one-fourth is served by the treatment plant. A combined sewerage system is used. Since 1911, about 6,870,000 gallons of sewage (mostly domestic) per day have been treated in Imhoff tanks, before being discharged into the Gera. Since this small stream is not always able to handle even this amount of settled sewage an activated-sludge plant was put into operation early in 1931, half of the sewage being biologically treated. The results of the purification are shown in the following table:

EXPERIMENTAL RESULTS OF RAW AND PURIFIED SEWAGE

	Raw Sewage	Settled Sewage	Activated Sludge Effluent	Plant Scale Experiments
pH	8.5	8.0	8.0	7.65
Ammonia Nitrogen	60.3	45.7	46.7	15.0
Organic Nitrogen	39.9	30.7	4.0	7.0
Nitrate and Nitrite Nitrogen	0	0	0.4	8.3
Oxygen Consumed	578	387	142	100
B. O. D. (7-day)	875	780	483	..
Suspended Solids	709	172	0	..

The river has been maintained in a far better condition as a result of the biological treatment. The sewage flows to the plant through two intercepting sewers, one carrying 66 gallons per second and the other 13 gallons. To avoid overloading, a storm water tank with a capacity of 812,000 cubic feet has been provided to store, temporarily, flow in excess of about 160 gallons per second. After normal conditions have been restored, two-thirds of the water stored flows back into the sewer. The remaining one-third must be pumped.

A two-inch bar screen collects about 17.5 cubic feet of solids per day. Then the sewage flows through a grit chamber, divided into two sections, each of which is about 46 feet long and 10 feet wide and which has an average water depth of about 3 feet. At a flow of about 10 cubic feet per second the velocity is about 4.33 inches per second. The tanks are cleaned every other week by hand and the grit obtained amounts to 35 cubic feet per day.

Eighteen Imhoff tanks, about 26 feet in diameter and 28 feet deep, are used. The settling capacity of each pair of tanks is 7770 cubic feet and the

digestion space, 11,800 cubic feet. For an average flow the velocity is about 0.1 inch per second and with storm flows, about 0.4 inch per second. The detention period with the above velocities is one hour 50 minutes and 30 minutes, respectively.

The new aeration tank is about 262 feet long and 102 feet wide and is divided into six double channels, the bottom of which consists of two adjacent semi-circles. The width of such a double channel amounts to about 16 feet and its depth under the water surface, about 7.5 feet. With a capacity of about 153,000 cubic feet there is a detention period of six hours for 5.3 gallons per second. The velocity in a horizontal direction is about one inch per second. In the aeration tank there are 54 paddle wheels, whose axes of rotation are parallel to that of the channel, giving to the water a spiral flow. The wheels consist of 40 laths about 6.5 feet long. The water level is maintained in the tanks at a height equal to the axes of the paddle wheels. The rotating paddles carry air into the liquid, providing good aeration. The paddle wheels have velocities of 10, 13.5 and 17 revolutions per minute and peripheral speeds of 3.3, 4.6 and 5.8 feet per second. The paddle wheels are arranged in groups of four and each group is operated by a 30 horsepower electric motor. The power required amounts to 8, 15 or 23 kilowatts, according to the speed of rotation of paddle wheels.

The sludge-sewage mixture passes from the aeration tank to the final settling tank for removal of sludge. These tanks consist of four hopper bottoms, whose area is about 1000 square feet and whose depth is 32.8 feet. The available space in the tank amounts to 20,000 cubic feet, resulting in a detention period of two hours and 50 minutes. Part of the settled sludge is returned to the aeration tanks and the excess pumped to the separate digestion tanks. There is a primary digestion period for fresh solids of 22 days. Then the sludge is pumped to a separate digestion tank having a capacity of 95,000 cubic feet, where it is mixed with excess activated sludge. The gas is collected. The sludge inlet pipe ends with an upward curve under the gas dome so that the sludge sprinkles over the surface and prevents the formation of a scum covering. The temperature of the digestion room is maintained at 25° F. by the use of hot water. Part of the wet digested sludge is sold for fertilizing purposes and the remainder is dried on drying beds.

The gas collected in the digestion room has an average methane content of 60 per cent. After the hydrogen sulphide is removed with bog iron filters, mercaptan is added and the gas is led through a meter to the gas tank, the capacity of which is 53,000 cubic feet.

There is a machinery and office building in the center of the plant, the main part of which is used for a machinery room, workshops, storerooms and machinists' rooms. The floor of this part of the building

is about 10 feet below the ground level. On the floor above are two offices, the laboratory and rooms for the workers. All operating machinery with the exception of the motors for the paddle wheels is placed in the machinery house so that it may be more easily watched. In addition to the gas from the digestion tanks, a supply from the municipal gas works is available and in this way the possibility of long interruptions in the operation is avoided.

Complete operating records are being kept. The cost of the new plant amounted to about $288,000.00. G. P. EDWARDS

The Nürnberg-Nord Treatment Plant

BY DR. ING. V. HANFFSTENGEL AND DIPL.-ING. WERNER MULLER

Gesundh. Ing., **55**, 517, 529, 543 (1932)

The Nürnberg-Süd sewage treatment plant, which was built during the period from 1913 to 1915, includes coarse screens, grit chambers, twenty Imhoff tanks with 81,200 cubic feet settling space and 169,000 cubic feet digestion capacity and drying beds 35,400 square feet in area. The population served in 1915 was 180,000. Although the population has only increased to 200,000 the plant is badly overloaded, due to the large amount of industrial wastes.

A second treatment plant, Nürnberg-Nord, was proposed, to treat part of the sewage from the Nürnberg-Süd plant and all the districts not hitherto served. The population included is 200,000. The original plans provided for Imhoff tanks, since the Nürnberg-Süd plant had been so satisfactory, but the ground water was found to be so close to the surface that settling tanks with separate digestion were decided upon. The digestion tanks were built mostly above the ground.

In the new plant, the coarse screens, sloping at 22°, have openings 2.0 inches wide and are cleaned by hand. The grit chamber is 82 feet long and the velocity of the flow is maintained at about one foot per second. It was intended to use the grit chambers only when necessary, but the large amounts of sand carried into the digestion tanks make their continual use advisable. Grit is removed by hand.

As originally planned, six settling tanks of the Mieder type were to be provided. These were to be 32.8 feet wide, 164 feet long and 6.5 feet deep, making a total of 212,000 cubic feet of settling space. However, four of these are now sufficient to handle the sewage from 200,000 people and the other two tanks will be added in about a year. The tanks have vertical side walls and the bottoms have a slope of 1:400 toward the inlet end, where there are two sludge sumps with a slope of 1:0.6. In order to permit

the sludge to slide smoothly into the hoppers, the sludge withdrawal pipes were placed on the side. The sewage is added and withdrawn over the entire width of the tanks. Adjustable overfall weirs aid in maintaining equal discharge over the entire width of the tank and baffles at the inlet end provide equal distribution over the whole tank. There is a wooden baffle 1.6 feet deep at the discharge end of the tank. The tanks are connected in pairs.

The operation of the plant is very simple. The sludge settles on the flat bottom and, once a day, is forced into the sludge hopper by the Leipzig type sludge removal equipment. This apparatus runs on a track placed on the side walls, at a speed of 0.8 inch per second. After starting, the machine runs automatically, stopping when the tank is cleaned and the sludge has been forced into the hopper. After the scraper is raised to the surface the machine goes back at a speed of 2.75 inches per second, forcing the scum to the discharge end of the tank. About five feet in front of the floating baffle the machine automatically stops and the scum, which now is collected between the scraper and the baffle, is drawn off into a receptacle at the side of the tank. After a tank is cleaned, which takes about one hour, the equipment is transferred to the next tank to be cleaned. The machine can be moved from tank to tank at a speed of about eight inches per second.

The sludge is withdrawn from the hoppers by hydraulic pressure but in case the sludge is particularly heavy, compressed air can be used. The scum can be forced into the digestion tanks at the same time as the fresh solids.

There are eight sludge-digestion tanks, each with a capacity of 26,500 cubic feet. The tanks are 32.8 feet square and arranged in groups of four. The tops of the digestion tanks are dome-shaped and covered with concrete and bitumin to make them gas-tight and to insulate them against loss of heat.

The sludge is removed from the digestion tanks by hydraulic pressure and compressed air may be used when necessary. Supernatant liquor may be drawn from different depths. Apparatus was installed in two of the tanks for sludge circulation and for breaking up scum. In front of each group of tanks there is a machine house, the ground floor of which contains the compressed air and heating apparatus and the second floor the sludge pumps and gas meters. Each tank has its own gas pipe and meter so that the sludge digestion of each tank, as measured by its gas production, can be observed. It is intended to build a small gas tank of about 5300 cubic feet capacity and to force the gas about 1.1 miles to the Nürnberg-Süd treatment plant, from where it will be pumped about 2.2 miles further to the municipal gas plant. For the present, the gas can only be used inside the treatment plant and the excess gas is allowed to escape into the air.

One group of tanks is equipped with heating coils for experimental purposes. Each tank has two heating coils, about 240 feet long, on the bottom and the lower part of the side walls, placed at a distance of about 10 inches from the bottom and the walls.

Sludge flows by gravity from the digestion tanks into the sludge drying beds, which have a total area of about 86,000 square feet. Individual beds, which at present, are only earthen basins, are about 33 feet wide and 197 feet long.

The plant treats about 11,600,000 gallons of sewage per day. The detention period in the settling tank is about 1.4 hours. Samples collected twice daily throughout the year showed the settleable solids in the raw sewage to be 5 cc. per liter.

The amount of sludge obtained daily amounted to about 7000–8800 cubic feet. The clarification process was not disturbed when the mechanical sludge equipment was used once a day. If the cleaning of the tank was omitted for one day the next time it was cleaned some light sludge could be seen floating but this did not noticeably affect the clarification action.

Special care had to be taken in putting the digestion tanks into operation because of the unfavorable season of the year, namely, January 31, 1931. The sewage had a temperature in February of from 46–48° F. during the day, whereas at night the temperature decreased to 39–41° F.

Several thousand cubic feet of Imhoff sludge from the Nürnberg-Süd plant were pumped into one group of four digestion tanks. The remaining four digestion tanks were not put into operation so as not to run the risk of filling the available digestion space with acid sludge. Naturally, the first group of tanks was overloaded. By the repeated addition of Imhoff sludge, gas formation was observed. However, by summer the sludge was acid, the average pH in March being 5.4 and in July 6.5. The sludge had an unpleasant, sour and fecal odor and, in order to avoid annoyance to the people living close by, it had to be removed as quickly as possible.

In August the second group of tanks was put into operation, the temperature at this time averaging 64° F. About 1000 cubic feet of Imhoff sludge was added to each tank and then 100 cubic feet of fresh sludge were added each day until the tanks were full. To avoid overloading at the beginning, 100 cubic feet of fresh sludge were added every other day to each tank for the first eight days. For the next fourteen days the addition was increased to 200 cubic feet every other day. During the first five weeks the pH varied between 7.3 and 7.5 and the temperature averaged 64° F. As soon as the second group of tanks was working properly, the first group was half emptied and filled with good Imhoff sludge. Then about 100 cubic feet of fresh sludge was added to each tank every other day.

The gas formation increased considerably and the pH rose to 7.2. By

fall the sludge drawn to the beds was well digested, black and odorless. As the gas meters were not connected during this starting period, the gas production could not be measured. After the tanks were operating satisfactorily, 56,500–85,000 cubic feet of gas per day was obtained without artificial heating.

The total cost of the plant amounted to about $275,000.00.

G. P. Edwards

Control of Sewage Condition by Chlorination

By Fred D. Bowlus and A. Perry Banta

Water Works and Sewerage, **79**, 369 (1932)

Since the sewage arriving at the Los Angeles County activated-sludge plant was several hours old, it was usually quite septic and caused a considerable reduction in plant capacity and many complaints from odors A mobile field laboratory was used to make tests for pH, hydrogen sulphide, temperature and chlorine demand, in order to indicate control points where rectification of sewage conditions would prove most economical and where individual waste contributions might be excluded or corrected.

Chlorine was applied at eight points and for the first time in two years, hydrogen sulphide was consistently absent from sewage entering the disposal plant, for at least a part of the day. The chlorine demand of the sewage reaching the plant was materially reduced. The B. O. D. decreased about 25 per cent, the odor nuisance was eliminated and the plant effluent showed a 70 per cent B. O. D. reduction over former conditions.

G. P. Edwards

A New Chemical Sewage Purification Process

By E. A. Cappelen Smith

Water Works and Sewerage, **79**, 420 (1932)

A new sewage purification process has been developed by the Guggenheim Laboratories. The process consists of four steps: (1) removal of suspended solids by coagulation with iron salts and lime; (2) disposal of sludge by filtration and incineration; (3) removal of basic nitrogen compounds with attendant groups containing carbon, hydrogen, sulphur, etc., by a special zeolite; (4) regeneration of the zeolite, including concentration of nitrogen compounds in the salt solution with a subsequent recovery of ammonia. The results from an experimental plant, with a capacity of 2500 gallons per day, showed a reduction of B. O. D. from 150

to 5 p. p. m. and a complete removal of suspended solids. Total nitrogen was reduced from 24–28 to 2 p. p. m. G. P. EDWARDS

Sewage Treatment at High Point, N. C.

BY E. H. MOSS AND C. W. MENGEL

Water Works and Sewerage, **79**, 433 (1932)

The City of High Point, N. C., is now operating two sewage treatment plants. The first one, placed in operation on the East Side in 1929, is of the separate sludge digestion, sprinkling filter type. The sewage, obtained from a population of 25,000, amounts to about 2.43 m. g. d. and contains a large amount of industrial wastes, especially from textile mills. The raw sewage has a B. O. D. of 358 p. p. m. and suspended solids of 224 p. p. m. The final plant effluent has an average B. O. D. of 24 p. p. m., 28 p. p. m. of suspended solids and contains 8.47 p. p. m. of nitrates and nitrites. An average of 165,000 cubic feet of gas is obtained per day.

The second plant, located on the West Side, was completed in 1930 and treats an average of 1.125 m. g. d. of sewage from a population of about 10,000. The sewage is entirely domestic, with the exception of some laundry wastes. The activated-sludge tanks are spiral flow type and about 1.40 cubic feet of air are required per gallon of sewage. The excess sludge is filtered and used for fertilizer. The raw sewage contained 161 p. p. m. of suspended matter and had a 5-day B. O. D. of 190 p. p. m. The final effluent contained 18 p. p. m. suspended solids and had a B. O. D. of 14 p. p. m. The nitrate-nitrite content was 1.86 p. p. m. G. P. EDWARDS

The San Antonio Sewage Treatment Plant

BY W. S. STANLEY

Water Works and Sewerage, **80**, 21 (1933)

The San Antonio treatment plant was put into operation in October, 1930. The sewage flow averages 19 m. g. d. from a population of 181,542. The plant consists of bar screens, grit chamber, preliminary settling tanks, spiral flow aeration tanks and final settling tanks. The primary settled sludge and the excess activated sludge are digested in separate digestion tanks equipped for artificial heating and gas collection. The digested sludge is dried on sand beds. The cost of construction was $939,328.75. The average cost, for operation only, per million gallons of sewage treated was $10.57. G. P. EDWARDS

Sewerage Commission—City of Milwaukee Metropolitan Sewerage Commission County of Milwaukee Report for the Year 1931

BY JAMES L. FEREBEE, CHIEF ENGINEER

When the Milwaukee sewage treatment works was designed, the population to be served in 1930 was estimated to be 589,000, with a sewage flow of 85 m. g. d. This was used as the design basis for the aeration system and for the sludge pressing and drying plant. The sewers, screens, grit chambers, channels and power-house building were built for a sewage flow of 200 m. g. d. As the population tributary to the plant for 1930 was 700,000, with a sewage flow of about 100 m. g. d., it was recommended that extensions be built to increase the capacity of all units to 154 m. g. d., the estimated flow for 1945.

In answer to a series of questions asked in 1930 by the Mayor of Milwaukee, Mr. D. W. Hoan, and by a member of his Advisory Council, Mr. H. P. Eddy's answers were in part as follows: (1) After the Milwaukee Sewage Treatment Plant was put in operation there was a marked improvement in the drinking water both before and after chlorination as shown by the bacterial counts at 37° on agar. (2) There are only small sludge deposits in Milwaukee bay, except near the mouth of the river. (3) The danger of contamination of the Milwaukee water supply by other cities along the lake is very slight. (4) A water filtration plant is needed at once, but the additions to the sewage treatment plant necessary to take care of the present flow are more desirable, if a choice must be made. (5) It is not desirable at the present time to develop a new process of sewage treatment for Milwaukee. (6) The best figures at the time (January, 1931) on the cost of producing Milorganite from activated sludge were: fixed charges and depreciation, $7.17 per ton, operating charges, $15.87 per ton, net income from sales, $16.17 per ton, or a net loss of $6.87 per ton.

A survey was made of the grease traps in restaurants to determine how efficient they were in keeping grease out of the sewers. All of the larger and most of the smaller restaurants were found to have grease traps, which were cleaned at intervals ranging from three days to a month or more. A few traps were never cleaned. Samples taken indicated that the traps were very effective in removing free grease, but that most of the grease passed through as a soap emulsion.

An Oliver filter was reconstructed so as to incorporate, as far as possible, the principle of the "Feinc" filter. This involved a change in the filtrate drainage facilities and a change in the method of removal of the

sludge cake. The "Feinc" filter used a tangential string take-off in place of the air blowing and scraping of the Oliver filter. The test indicated that from the standpoint of cake production and moisture there was no appreciable difference between the two filters.

Tests were made on aerating activated sludge as an aid to filtering. Aeration periods between 12 and 36 hours were used, with suspended solids between 0.6 and 1.2 per cent, the desired dilutions being obtained by the addition of sewage. Fifteen per cent of the accumulated sludge from each previous test was retained in the tanks.

"The conclusions drawn from the tests were about as follows:

1. Reaeration of sludge at above stated concentrations was not effective as measured by our standard filtration tests.
2. Reaeration indicated that sludge condition has been somewhat benefited, as shown by the decreased acid requirement for conditioning to optimum pH.
3. The tests showed that sludge of about 0.8 per cent solids concentration gave the best results on reaeration.
4. Detention periods less than 14 to 16 hours showed little improvement in sludge condition."

Studies were made on the protozoan life in activated sludge, with temperatures maintained at 45° and 70° F. to simulate winter and summer conditions. As yet no relation has been shown between the protozoan life in sludge and its physical condition.

Tests were made of the availability of the phosphate in Milorganite, to learn whether compounds of iron which may be present tend toward reversion on ammoniation, with a lowering of availability of the phosphate. The results proved that this did not occur, but that on the contrary when a mixture of Milorganite and superphosphate was ammoniated, the Milorganite absorbed some of the ammonia and thereby decreased the amount of phosphate which was reversed to a non-available state.

The report contained reprints of the following papers:

"Descriptive Review of the Work of the Milwaukee Sewerage Commission, 1914–1928" by D. W. Townsend; "Bond Strength of Wood Piles in Concrete" by R. R. Lindahl; "The Design of Aeration Units and Sedimentation Tanks for the Activated Sludge Sewage Disposal Plant at Milwaukee, Wisconsin" by D. W. Townsend; "Settling Characteristics of Activated Sludge" by D. W. Townsend; "New Sludge Removal Apparatus Developed at Milwaukee" by D. W. Townsend and J. Brower; "Large Scale Scientifically Controlled Screenings Digestion Experiments at Milwaukee, Wisconsin" by D. W. Townsend and Dr. Willem Rudolfs; and "Proposed Disposal of Sewage Grit and Coarse and Fine Screenings by Incineration" by D. W. Townsend.

"Fine Screenings Digestion-Plant Scale" by H. M. Heisig

The demonstration plant consisted of four square hopper-bottomed concrete tanks, each of 35,000 gallons capacity. Heating coils and gas collecting and measuring devices were provided. Gas-fired boilers for heating the circulating water used the collected gas and also city gas when needed. Screenings were fed to the tanks by means of ejectors equipped with special devices to prevent air from being forced into the digestion tanks. Runs were made at 85°, 145° and 130° F. and at 104° F. with trypsin and pepsin. In order to avoid a delay in starting, digested sludge was imported from Antigo, Wisconsin, as a seed. No sludge was taken from the tanks during the runs as it rose to the water surface and stayed there as an impervious blanket. Small samples were taken for analyses but gas production was used as a measure of the degree of digestion attained. For the pepsin digestion, the tank contents were adjusted to a pH of 3.0 with sulphuric acid. This was so destructive to the tank and piping that the test was abandoned before any results were obtained. A table from the report gives the results for the other conditions.

Run	Temp., Deg. F.	Tank	No. of Days of Run	Total Dry Solids Charged, Pounds	Daily Dry Solids Charged, Max.	Daily Dry Solids Charged, Aver.	Total Gas Produced, Cu. Ft.	Cu. Ft. Gas per Pound Dry Solids Charged
Straight Digestion	85	1	267	69,314	404	260	369,300	5.72
Straight Digestion	104	3	121	27,618	397	228	192,100	6.95
Trypsin	104	2	172	41,898	394	244	199,400	4.76
Thermophylic	145	4	99	29,868	424	302	164,600	5.50
Thermophylic	130	4	349	87,519	661	251	605,300	6.98
Thermophylic	130	3	174	74,928	838	430	475,200	6.30
Thermophylic	130	2	175	57,226	646	327	399,200	6.97
Thermophylic	130	1	119	25,160	372	211	221,900	8.80

The gas produced averaged 38.2 per cent carbon dioxide, 53.8 per cent methane, 1.4 per cent oxygen, 5.2 per cent nitrogen and small amounts of hydrogen, carbon monoxide and illuminants. The ratio of oxygen to nitrogen suggests that the source of these gases was the air introduced with the screenings.

Attempts were made to break up the scum blanket which formed on top of the liquid and which contained practically all of the solids added. Recirculation was tried, the blanket was broken up by hand and saturators were installed to distribute the tank liquid over the surface of the scum, but all to no purpose. A scum rack installed in one of the tanks was broken up and the heating coils were damaged several times by this heavy blanket. About one-third of the blanket was above the water level, so that it was impossible to remove the screenings other than by

emptying the tanks and breaking up the mass with high pressure water jets, which was a slow and laborious process.

The conclusion drawn was that large scale digestion did not produce a satisfactory product and was not recommended for the disposal of the fine screenings at Milwaukee.

"Fine Screenings Digestion, Earp-Thomas Process"

The digester for this process consisted of an insulated steel tank 6 ft. in diameter and 9 ft. 2 in. high, with four decks. A vertical shaft through the center of the tank was equipped with a pair of arms at each deck. Attached to these arms were plows for mixing the screenings and discharging from deck to deck through adjustable openings. The location of the discharge openings was at the middle of number 1 and 3 decks and at the periphery of number 2 and 4 decks. The shaft made one revolution in two minutes. The floors were provided with slotted false bottoms for drainage, the false bottom occupying the entire floor area of number 1 and 3 decks and a portion only of number 2 and 4 decks. Six-inch ventilating pipes were provided near the top of each deck.

The raw screenings were delivered to the digester at 93 per cent water and after being allowed to drain for a short time were spread over the surface of the number 1 deck by the plows and the inoculating material added. For each ton of wet raw screenings about 125 pounds of a mixture were added which consisted of peat, 80 pounds, calcium carbonate, 15 pounds, calcium sulphate, 20 pounds, and bacterial culture, 10 pounds. As soon as the bacterial action became vigorous, as indicated by the temperature, the charge was plowed to the next lower deck and a new charge was added. After the preliminary run it was found desirable to add some of the finished product to the charge in order to make it easier for the plows to mix and move the material. Also the depth of the charge on each deck was increased from 6 inches to 12 inches in order to retain the heat as produced. A 50-hour detention period was adopted at first, but later it was found necessary to increase the period. Plowing and ventilating increased the bacterial activity but cooled the material. It was desired to attain a temperature of 160° F. in the mixture but 145° to 150° was the best that could be reached with a unit of this size.

The product from the digester had a moisture content of about 62 per cent and after air-drying it was lumpy, not friable. It was odorless and remained odorless on standing. The material was too low in nitrogen to have much value as a fertilizer. No measurable change in the availability of the nitrogen in the screenings took place in the process. The process as demonstrated was not recommended for the Milwaukee Sewage Disposal Plant.

"The Design, Operation and Maintenance of Combined Sewage Intercepting Structures" by W. E. Kroening

As the City of Milwaukee had a combined system of sewers, it was necessary to install control devices to limit the storm flow from the city sewers to the treatment plant intercepting sewers. The device adopted consisted of a butterfly gate, with a horizontal shaft at about a third of the distance from the bottom of the gate. The gate was balanced by a weight attached to the lower part of the leaf. A nearly horizontal bottom plate was provided which could be raised or lowered at one side by means of adjusting screws to adjust the storm-flow opening and a stop was provided to limit the opening of the gate for dry-weather flows. The gate housing was of precast concrete. In action the gate was closed by the unbalanced pressure on the top half when the water level of the sewer was raised under storm conditions. The gates were set to close with a storm flow in excess of 0.01 inch an hour. The control devices were inspected every week and after storms. The mechanism is simple and inexpensive to construct and very easy to maintain. Charts and data are given for the design.

Abstractor's Note: It is apparent, however, in looking over the charts and data given, that this type of control does not have quite as good flow characteristics as some float-operated types. The principal objection is that the discharge rate which will allow a gate to open must be somewhat less than the flow which will close the gate. RALPH J. BUSHEE

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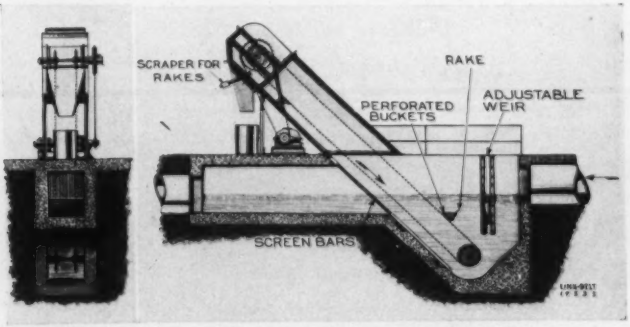

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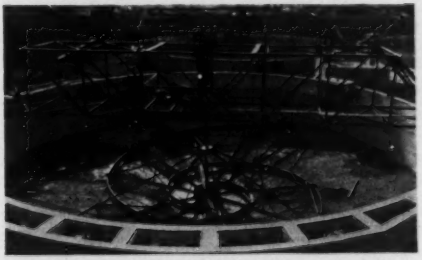

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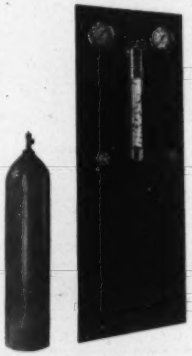

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